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CORRECTION

Volume 42, page 303 (May, 1914), the Precipitation Departure for the West Gulf States should have a *plus* sign.

MONTHLY WEATHER REVIEW

Editor, ALFRED J. HENRY

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MAY, 1929

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CORRELATION BETWEEN RAINFALL AND RUN-OFF

By J. W. SHUMAN, Mem. Amer. Soc. C. E.

The problem of determining the relationship between rainfall and river run-off has engaged the attention of many investigators (1). Attempts have been made to derive equations that would enable one to compute the run-off from the amount of rainfall on the drainage basin. Our great need for some knowledge of this relationship is brought about due to the inadequate length of most river-gaging records. Rainfall data are generally available for a long term of years, whereas river gaging records usually cover only brief periods, 4 to 10 years. The uncertainties of a solution of this problem are acknowledged by every investigator and by every book on hydrology. The methods and equations that are given can only be used as a rough guide, and no attempt is made to get very far into the problem or to show the extent of the fitness of the proposed method.

In considering this subject, we are faced at the outset with raw data that are admittedly inaccurate. It is impossible to place enough rain-gages over a drainage area to guarantee an absolute measure of the amount of precipitation. Also, the best methods in vogue for determining the quantity of the "sec.-feet" run-off will not give an absolute measure. True, if the river be a mere stream and a good wier can be thrown across it, fairly accurate results can be secured; but, in general, reliance is placed in floats and velocity meters. Even with good meters, when the uncertainties of securing the true section of the stream, are taken into account, as well as the changing conditions of the river bed or the control, it is easy to understand why good engineers make some reductions in their figures, in order to be on the safe side. In other words, the accuracy of the data is recognized as uncertain.

Because no dependable solution of this problem has been put forth, hydrologists have been obliged to resort to the scheme of taking what river run-off records were available and making therefrom a duration curve, showing variation of discharge with percentage of time. They then might give some consideration to the amount of rain that fell during the period embraced by the duration curve data, as compared to the long-time mean, and this would be about all that they could do, unless some probable discharges were worked out on the probability theory.

The relationship between rainfall and run-off is evidently a very complicated one, and to date has defied the efforts of our ablest investigators to set down in mathematical terms just what it really is. It was noticed a long time ago that the calendar year run-off (January to January) did not always keep step with the current calendar year rainfall, and the "water year," October to October, was adopted as a better 12-months period to consider. But even with this change, not much was gained. It is very likely that we may never be able to derive an exact expression defining the relationship, but it is the hope of the writer in what follows to show some progress in this problem.

It is now two years since the writer first saw an article, by A. Streiff (2), that dealt with the various cycles in our weather elements. This was the starting impulse that led to the special studies in rainfall as outlined below. Instead of inspecting columns of rainfall data, typed on a sheet of paper, the data were studied by preparing a graph, plotting the values as ordinates against time as abscissa, and connecting the points by a smooth curve. Run-off was treated the same way, which led eventually to showing the probable fact run-off *is* proportional to rainfall but *lags* behind it in time.

Inasmuch as the ideas exploited herewith all hinge upon this lag, it is advisable to promptly define exactly what is meant. By *calendar-year* run-off, or rainfall, reference is made to the amount that discharged or fell for the period from January 1 to January 1. In plotting the magnitude of these values, no consideration is given as to what date in the year these plotted points are assigned. Considering either rainfall or run-off on the graph, the plotted point simply represents the magnitude of the value. Thus a smooth curve drawn through the various plotted points is considered to have no significance between two adjacent points. By the term *rainfall year*, reference is made to a 12-months period of rainfall that does not necessarily coincide with the calendar year period. As to the lag, I find that the calendar-year run-off is proportional, *in a higher degree*, to a 12-months rainfall period, if the latter be advance one or more months, than it is to the current calendar-year rainfall; viz, if the run-off lags four months behind the rainfall, it is meant that the calendar-year run-off is proportional to the rainfall from September 1, of the previous year, to September 1 of the current year.

Attempts to discover any workable relationship between the variables we are considering, using periods of time less than one year, have been fruitless, so that I have considered in the following studies only the annual values. The nature of this lag will be disclosed in a study of the Tennessee, Yadkin (N. C.), and Root (Minn.), rivers, and of the rainfall and run-off data of the Wagon Wheel Gap (Colo.) experiment. It is convenient to think of this run-off lag as analogous to electrical inductive effect. In a given circuit, through which an alternating current is being sent, by proper insertion in the circuit of inductance or capacity, the current may be made to either lag

or lead, with respect to the impressed voltage, high inductance inducing a large lag. In investigating various sized streams, this lag seems to vary from 3 to 6 and even 9 months.

Acceptance of the fact of run-off lag requires thinking of the regimen of a stream in a modified way. Of course the rainfall that occurs after the rainfall year has ended, contributes to the calendar year run-off. It must be admitted that a lapse of time must take place before run-off can appear. We think of this time as relatively short, because streams usually respond at once to pronounced rainfall. However, this response is not the lag, as this momentary response has but little if any effect on the stream's mean annual flow. If a given section of the country has sufficient rainfall, and the slope of the land is proper, a river will eventually result, but this will not occur with a series of spasmodic rainstorms, even though some of them be very severe. In order that a river may be one in fact it requires the presence of water that has fallen some time back.

RAINFALL YEAR AND LOCATING THE RUN-OFF LAG

As stated before, the rainfall year is a 12-months period. For a 2-months lag of run-off, the corresponding rainfall year would be from November 1 of the previous run-off year to November 1, of the current year; for 6-months lag, it would be from July 1 to July 1, etc. Care should be taken to secure as many rainfall stations as possible over the drainage area of the river. If a large enough number of such stations is available, it will not be necessary to weight the records. For example, in the Tennessee River study below, the rainfall records were first weighted, and later used just as printed. There seemed to be very little discrepancy, the maximum being less than 2 per cent. Thus, by being able to use the records just as printed, a great deal of labor is saved.

In order to work most efficiently proper attention must be given to the scales employed in making the graphs. The writer plots the run-off values as ordinates one-half inch apart, and so chooses the vertical scale as to give the resulting smooth curve drawn through the plotted points considerable amplitude up and down. A graph is first made of the calendar year run-off. Next the rainfall records are prepared for use. Suppose one has 10 stations, and inspection shows that they are bona fide records (no estimates inserted, as is frequently the case). Suppose, further, that the run-off records cover a period only 6 years long, and ceased 6 years ago, and that we desire some index of what the run-off has been in the past 6 years. We prepare a blank page with the 10 stations listed at the left, one below the other, and opposite the monthly headings at the top of the page, we set down the monthly rainfalls for each of the 12 years. Each year will be made up of 10 stations, 12 months each. These monthly columns for each year are now averaged, and a fresh memo prepared, showing the mean rainfall for each month, for each year, set down in a vertical column.

The total calendar year rainfall is now secured for each year, and marked conveniently at the side of each year's column. Just for curiosity we might plot the calendar year totals of rainfall on a piece of thin paper, laid over the graph of the run-off, to see if the curves resemble each other. Very likely we will find here and there some resemblance, but it will most likely extend only over a year or two, and then the values will be opposite. We do not know what the lag is, but we start out with the assumption, say, that it is three months. A table is prepared of a 12-month rainfall period, running from October 1 to October 1, for each of the 12 years, and we try plotting again on a piece of thin paper laid over the run-off graph, setting down the first rainfall year value on the first run-off value ordinate. Various shifts of the rainfall year are thus made until we find the best synchronism of the curves. This sounds rather complicated, but after the work of preparing the rainfall data, as outlined above, is done, the method is quite simple and quick. If no synchronism can be detected, no matter what lag is given, the chances are that either an error has been made in the preparation of the rainfall data, or in securing the total or mean run-offs, or that the records themselves are inaccurate; for we must bear in mind the nature of the data with which we deal.

TENNESSEE RIVER

This river has been gaged since 1874, and the records are probably the most reliable of any stream in the United States. Footnotes to the data state that there was no artificial regulation of the flow prior to October 22, 1913; but that after that date the low flows might be affected by the Hales Bar lock and dam. This should be a good river with which to test this lag idea.

The discharge is taken as at Chattanooga, from Bulletin No. 34, Water Resources of Tennessee, issued by the State. The drainage area above Chattanooga is about 21,400 square miles. Eleven United States Weather Bureau station records were used—Chattanooga, Decatur, Charleston, Kingston, Clinton, Tazewell, Knoxville, Bryson City, Bluff City, Hot Springs, and Asheville. The mean calender-year run-off was computed from the records, and plotted in curve No. 1, Figure 1. The complete rainfall records for the above 11 stations are not available farther back than 1907. Table 1 gives the mean annual run-off and the 12 months rainfall over the basin for a 3½ months lag, as it was found that this lag brought about the highest state of agreement between the curves. These data are given in columns 2 and 3, from 1908 to 1926. The rainfall values in column 3 are plotted in curve No. 2, Figure 1. The similarity of the curves may be noted as almost perfect with the exception of the year 1915–16.

TABLE 1.—*Showing observed mean annual discharge of Tennessee River at Chattanooga, Tenn.; annual rainfall over drainage basin; mean annual computed discharge, from equation, Second-feet=879.2×rainfall−5809; and accuracy of results*

Year	Observed second-feet	Rainfall [1]	Computed second-feet	Per cent column 4 is of column 2
(1)	(2)	(3)	(4)	(5)
1908	39,366	47.05	35,557	90.5
1909	47,342	60.31	47,216	99.8
1910	29,185	43.71	32,621	111.8
1911	34,758	45.66	34,335	98.8
1912	40,175	56.73	44,059	109.7
1913	34,882	47.19	35,680	102.2
1914	27,512	40.05	29,403	106.8
1915	37,058	48.89	37,175	100.2
1916	38,691	54.48	42,090	108.8
1917	43,292	57.06	44,358	101.7
1918	36,233	42.11	31,214	86.2
1919	37,242	50.49	38,582	103.5
1920	50,183	58.96	46,029	91.9
1921	35,050	44.89	33,658	96.0
1922	43,003	50.64	38,714	90.1
1923	41,249	53.87	41,554	100.6
1924	35,583	48.52	36,850	103.7
1925	23,110	34.72	24,717	107.0
1926	31,294	47.57	36,014	115.2

[1] 3½ months ahead of run-off.

In order to secure a measure of how close is the correlation of the curves thus depicted, we compute the correlation coefficient as given in Table 2. We have dealt here with data from 1908 to 1925, so as to compute the 1926 discharge.

A correlation coefficient of +0.9112 is found, indicating a high state of agreement. Assuming linear regression, and using mean values, we secure the regression equations for both second-feet and rainfall,

(I) Second-feet = 879.2 × rainfall − 5,809
(II) Rainfall = 0.000944 × second-feet + 13.83.

Using equation (I), we have computed the discharges for the period given in Table 1, and give same in column 4. The percentages of the computed to the observed values are given in column 5. The greatest deviation shown is 15.2 per cent, for 1926. Exclusive of this date, the computed values run remarkably close to the observed.

The trend of flow[1] in this well-gaged river is shown in curve A, Figure 1, from 1875 to 1926, and the Brückner cycle is plainly visible in the graph, as suggested by the dotted line. Streiff (2), (3), has shown how the run-off can be estimated in the future for a river of this class, with the available discharge records to work with.

[1] The trend of flow is found by drawing a median line through the graph; in other words, it is a form of smoothing.—ED.

TABLE 2.—*Correlation between rainfall and run-off, Tennessee River*

Year	Run-off—X	Rain-fall—Y	x	y	x^2	y^2	xy +	xy −
1908	39,366	47.05	+1,927	−2.14	3,713,300	4.58		4,123.8
1909	47,342	60.31	+9,903	+11.12	98,070,000	123.65	110,121.4	
1910	29,185	43.71	−8,254	−5.48	68,127,000	30.03	45,231.9	
1911	34,758	45.66	−2,681	−3.53	7,188,000	12.46	9,463.9	
1912	40,175	56.73	+2,736	+7.54	7,486,000	56.85	20,629.4	
1913	34,882	47.19	−2,557	−2.00	6,538,000	4.00	5,114.0	
1914	27,512	40.05	−9,927	−9.14	98,545,000	83.54	90,732.8	
1915	37,058	48.89	−381	−.30	145,161	.09	114.3	
1916	38,691	54.48	+1,252	+5.29	1,567,500	27.98	6,623.1	
1917	43,292	57.06	+5,853	+7.87	34,259,000	61.94	46,063.1	
1918	36,233	42.11	−1,206	−7.08	1,454,500	50.13	8,538.5	
1919	37,242	50.49	−197	+1.30	38,809	1.69		256.1
1920	50,183	58.96	+12,744	+9.77	162,410,000	95.45	124,508.9	
1921	35,050	44.89	−2,389	−4.30	5,707,400	18.49	10,272.7	
1922	43,003	50.64	+5,564	+1.45	30,958,000	2.10	8,067.8	
1923	41,249	53.87	+3,810	+4.68	14,185,000	21.90	17,830.8	
1924	35,583	48.52	−1,856	−.67	3,444,800	.45	1,243.5	
1925	23,110	34.72	−14,329	−14.47	205,330,000	209.38	207,340.6	
Means	37,439	49.19			41,620,415	44.71	711,896.7	4,379.9
							−4,379.9	
							+707,516.8	

$(41{,}620{,}415)^{\frac{1}{2}} = 6{,}451.3 = \sigma_x \qquad r_{xy} = \frac{+707{,}516.8}{18 \times 6{,}451.3 \times 6.686} = +.9112$

$(44.71)^{\frac{1}{2}} = 6.686 = \sigma_y \qquad b_{xy} = \frac{0.9112 \times 6{,}451.3}{6.686} = 879.2$

$b_{yx} = \frac{0.9112 \times 6.686}{6{,}451.3} = 0.000.944$

Regression equations:
(I) Second-feet = 879.2 × rainfall − 5,809
(II) Rainfall = 0.0009444 × second-feet + 13.83

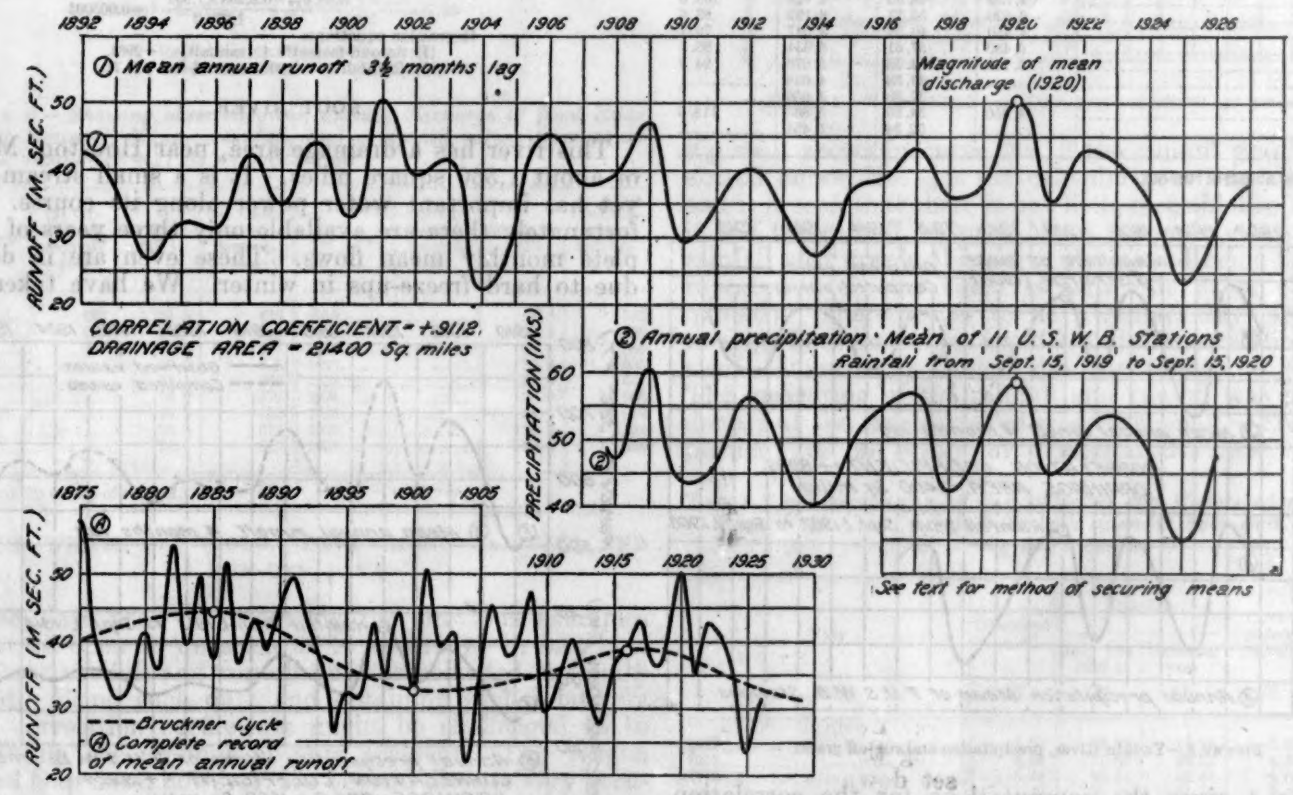
1892 1894 1896 1898 1900 1902 1904 1906 1908 1910 1912 1914 1916 1918 1920 1922 1924 1926
① Mean annual runoff 3½ months lag
Magnitude of mean discharge (1920)
RUNOFF (M. SEC. FT.)
50
40
30
20
CORRELATION COEFFICIENT = +.9112
DRAINAGE AREA = 21400 Sq. miles
② Annual precipitation Mean of 11 U.S.W.B. Stations
Rainfall from Sept. 15, 1919 to Sept. 15, 1920
PRECIPITATION (INS.)
60
50
40
See text for method of securing means
1875 1880 1885 1890 1895 1900 1905 1910 1915 1920 1925 1930
RUNOFF (M. SEC. FT.)
50
40
30
20
Bruckner Cycle
Ⓐ Complete record of mean annual runoff

FIGURE 1.—Tennessee River, precipitation and run-off graph

YADKIN (N. C.) RIVER

This river has a drainage area above Salisbury, N. C., of about 3,400 square miles, and the gaging records at Salisbury are supposed to be of fair accuracy, with no ice troubles. Records are available in the United States Geological Survey's Water Supply Bulletins, from 1903 to 1909, inclusive, for the year 1912, and from 1914 to 1919, inclusive. There are gaps in the record for 1910 and 1911 and for 1913. What will this method do for us here? The records are of scarcely continuous enough length to utilize Streiff's method. Rainfall records are used from Salisbury, Settle, Statesville, Winston-Salem, Brewers, Lenoir, and Mount Airy—seven in all. By the process outlined, the lag of run-off behind rainfall in this case is found to be about four months. Table 3 lists the data.

TABLE 3.—*Showing observed mean annual discharge of Yadkin River, near Salisbury, N. C.; annual rainfall; computed mean annual discharge from regression equation, second-feet=161.4× rainfall−2964.; and accuracy of results*

Year	Observed second-feet	Rainfall [1]	Computed second-feet	Per cent column 4 is of column 2
(1)	(2)	(3)	(4)	(5)
1903	6,850	58.77	6,521	95.2
1904	2,873	39.69	3,442	119.7
1905	4,539	48.90	4,928	108.6
1906	6,620	56.73	6,192	93.6
1907	4,480	40.34	3,547	79.2
1908	6,480	57.61	6,334	96.1
1909	5,710	53.53	5,676	94.4
1910	----------	43.38	4,038	----------
1911	----------	37.30	3,056	----------
1912	4,950	54.69	5,863	118.5
1913	----------	52.34	5,484	----------

[1] 4 months ahead of run-off.

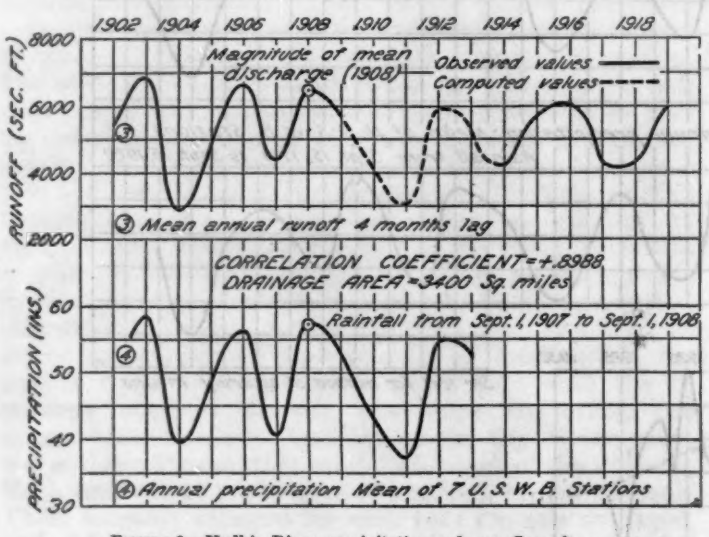

FIGURE 2.—Yadkin River, precipitation and run-off graph

Table 4 gives the computations for the correlation coefficient between the rainfall and run-off data, which has been plotted in curves No. 3 and 4 in Figure 2. We have taken the data only up to and inclusive of the year 1913, although doubtlessly the correlation would have been closer had we included the balance of the record. However, we wish merely to show the method, and as it is, we secure a correlation coefficient of +0.8988. The regression equations are:

(I) Second-feet = 161.4 × rainfall − 2964.
(II) Rainfall = 0.005 × second-feet + 25.71.

Using equation (I) we compute the discharge in second-feet, and thus fill in the gaps. Table 3 shows the computed values in column 4, and their accuracy with respect to the observed values in column 5. Here we note a maximum discrepancy of 19.7 per cent. This may apply to the gap computed values, too; but nevertheless, our computed values are better than wild guesses. Had we taken the complete record up to 1919, we probably would have secured a better fit.

TABLE 4.—*Correlation between rainfall and run-off, Yadkin River*

Year	Run-off—X	Rain-fall—Y	x	y	x^2	y^2	xy +	xy −
1903	6,850	58.77	+1,537	+7.49	2,362,369	56.10	11,512.1	----------
1904	2,873	39.69	−2,440	−11.59	5,953,600	134.33	28,279.6	----------
1905	4,539	48.90	−774	−2.38	599,076	5.66	1,842.1	----------
1906	6,620	56.73	+1,307	+5.45	1,708,249	29.70	7,123.2	----------
1907	4,480	40.34	−833	−10.94	693,889	119.68	9,113.0	----------
1908	6,480	57.61	+1,167	+6.33	1,361,889	40.07	7,387.1	----------
1909	5,710	53.53	+397	+2.25	157,609	5.06	893.3	----------
1912	4,950	54.69	−363	+3.41	131,769	11.63	----------	1,237.8
Mean	5,313	51.28	----------	----------	1,621,056	50.28	66,150.4	1,237.8
							−1,237.8	
							+64,912.6	

$(1{,}621{,}056)^{\frac{1}{2}} = 1{,}273.2 = \sigma_x$ $\quad r_{xy} = \frac{64{,}912.6}{8 \times 1{,}273.2 \times 7.091} = +0.8988$

$(50.28)^{\frac{1}{2}} = 7.091 = \sigma_y$ $\quad b_{xy} = \frac{0.8988 \times 1{,}273.2}{7.091} = 161.4$

$b_{yx} = \frac{0.8{,}988 \times 7.091}{1{,}273.2} = 0.005005$

Regression equations:
(I) Second-feet = 161.4 × rainfall − 2964.
(II) Rainfall = 0.005 × second-feet + 25.71.

ROOT RIVER

This river has a drainage area, near Houston, Minn., of about 1,560 square miles. It is a small stream, and yet has important water power along its course. Unfortunately there are available only three years of complete monthly mean flows. These even are in doubt, due to hard freeze-ups in winter. We have taken the

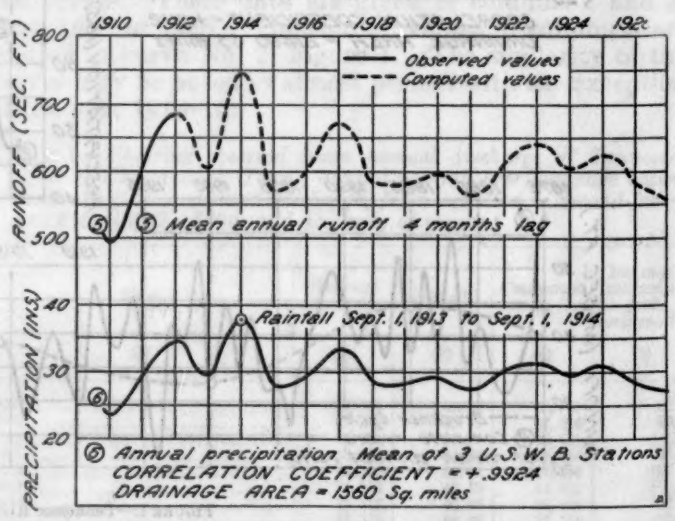

FIGURE 3.—Root River, precipitation and run-off graph

mean annual discharge for the years 1910, 1911, and 1912 as a mean of the United States Geological Survey records and of Adolph F. Meyer's computed results (from his book on hydrology). This is all we have to work with, if we would like some idea of the discharge variation in the following years.

Rainfall data were averaged from Caledonia, Grand Meadow, Rochester, and Chatfield, Minn. The run-off

lag here was again found to be about four months. In Figure 3, curve No. 5 shows the run-off and curve No. 6 the rainfall graphs. Of course with but three records to consider, we naturally expect to find a high correlation, and are not surprised when the computations in Table 5 disclose a figure of +0.9924. The computed values are shown in Table 6, and naturally for the three known years, the values are very close to observed. As for the balance of the time, we can only assume an accuracy of say 10 to 15 per cent for the computed values from 1913 to 1927. The data on which we have based our relations is meager, but if we reflect upon the results obtained with the Tennesesee River, we can have greater confidence in the results we have secured. Again, it is a great deal closer to the actual discharge than any guess.

TABLE 5.—*Correlation between rainfall and run-off, Root River*

Year	Run-off—X	Rainfall—Y	x	y	x^2	y^2	xy +	xy −
1910	493	23.5	−104	−5.9	10,816	34.81	613.6	
1911	610	29.9	+13	+.5	169	.25	6.5	
1912	689	34.8	+92	+5.4	8,464	29.16	496.8	
Means	597	29.4			6,483	21.41	1,116.9	0.00

$(6{,}483)^{\frac{1}{2}}=80.52=\sigma_x \qquad r_{xy}=\frac{1116.9}{3\times 80.52\times 4.627}=+0.9924$

$(21.41)^{\frac{1}{2}}=4.627=\sigma_y \qquad b_{xy}=\frac{.9924\times 80.52}{4.627}=17.39$

Regression equation for discharge:
(I) Second-feet = 17.39 × rainfall + 86.

TABLE 6.—*Showing observed mean annual discharge of Root River near Houston, Minn.; rainfall, and computed values from equation: second-feet = 17.39 × rainfall + 86*

(1) Year	(2) Observed second-feet	(3) Rainfall [1]	(4) Computed second-feet	(1) Year	(2) Observed second-feet	(3) Rainfall [1]	(4) Computed second-feet
1910	493	23.5	495	1919		28.5	582
1911	610	29.9	606	1920		29.5	599
1912	689	34.8	691	1921		27.8	569
1913		29.6	605	1922		30.3	613
1914		38.1	749	1923		31.9	641
1915		28.0	573	1924		29.9	606
1916		29.7	602	1925		31.2	629
1917		34.0	677	1926		28.8	584
1918		28.5	582	1927		27.0	556

[1] 4 months ahead of run-off.

WAGON WHEEL GAP (COLO.) EXPERIMENT RAINFALL AND RUN-OFF DATA

The data used in discussing the previous examples might be open to question as to accuracy—in fact it is ordinary rainfall and run-off data as collected and published. Using such data and obtaining such relatively high correlation coefficients might be challenged as to results on the grounds of pure accident. The Wagon Wheel Gap data, however, are beyond dispute very accurate. For the conditions obtaining in the securing of this data, reference should be made to Supplement No. 30 of the MONTHLY WEATHER REVIEW.

With these precise data of rainfall and resulting run-off, if we can secure a high correlation coefficient, it should lend reality to the claims here set forth. We will consider watershed A, as this was left untouched during the period of the experiment, whereas the B watershed was denuded after half of the time had expired. Watershed A has an area of about 222 acres, the run-off consisting of a streamlet fed by several springs, and measured by means of a V-notch wier, carefully calibrated. Table 7 gives, for the period 1912 to 1925, inclusive, the total run-off in inches over the area; the calendar year and the July 1 to July 1 year rainfall; the computed run-off from the regression equation derived, and the accuracy of the results.

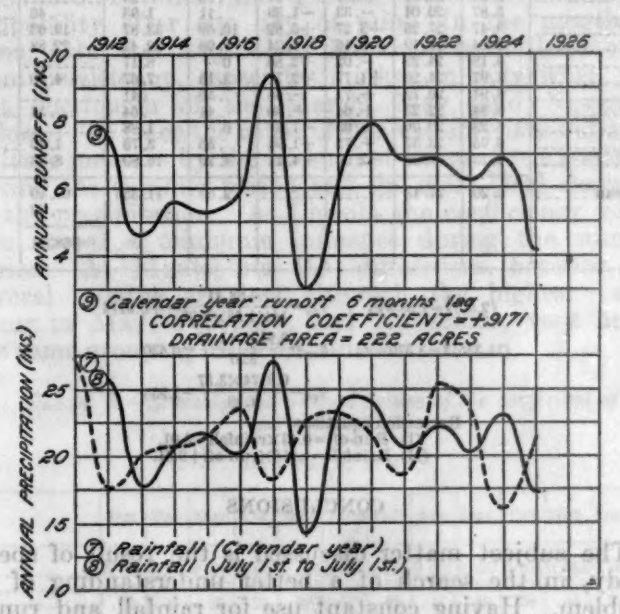

FIGURE 4.—Wagon Wheel Gap, Colo., graph of rainfall and run-off

Figure 4 shows in curve No. 9 the run-off graph. The dotted curve, No. 7, is the calendar-year rainfall graph, and it is seen that there is but little resemblance between it and the run-off. Curve No. 8 is the July 1 to July 1 rainfall year graph, this particular period being found by repeated trial (the same as with the other examples quoted). There seems to be a remarkably close relationship between curves 8 and 9, and the correlation coefficient, computed in Table 8 discloses this to be +0.9171. The measuring of the rainfall and run-off was precisely done, but the area involved was very small.—From Supplement No. 30, MONTHLY WEATHER REVIEW.

TABLE 7.—*Showing run-off in total inches over Watershed A, Wagon Wheel Gap, Colo.; rainfall for both calendar year and July 1 to July 1 year; computed results and accuracy*

Year	Observed run-off	Rainfall		Computed run-off	Per cent column 5 is of column 2
		July 1 to July 1	Calendar year		
(1)	(2)	(3)	(4)	(5)	(6)
1912	7.57	25.67	17.94	8.02	106.3
1913	4.64	17.86	20.22	4.67	100.6
1914	5.61	20.84	20.88	5.95	106.0
1915	5.33	21.94	21.56	6.42	120.0
1916	5.87	20.04	23.62	5.61	95.6
1917	9.47	27.25	18.44	8.71	92.0
1918	3.04	14.19	22.87	3.09	101.6
1919	6.18	24.29	23.31	7.43	120.3
1920	7.97	24.20	21.64	7.40	92.8
1921	6.91	20.79	18.52	5.93	85.8
1922	6.84	22.23	25.38	6.55	95.7
1923	6.23	20.06	23.42	5.62	90.3
1924	6.95	23.37	16.00	7.04	101.3
1925	4.15	17.32	21.34	4.44	106.9

TABLE 8.—*Correlation coefficient between rainfall and run-off, Wagon Wheel Gap experiment, Watershed A*

Year	Run-off—X	Rainfall—Y	x	y	x^2	y^2	xy +	xy −
1912	7.57	25.67	+1.37	+4.24	1.88	17.98	5.81	
1913	4.64	17.86	−1.56	−3.57	2.43	12.74	5.57	
1914	5.61	20.84	−.59	−.59	.35	.35	.35	
1915	5.33	21.94	−.87	+.51	.76	.26		0.44
1916	5.87	20.04	−.33	−1.39	.11	1.93	.46	
1917	9.47	27.25	+3.27	+5.82	10.69	33.87	19.03	
1918	3.04	14.19	−3.16	−7.24	9.99	52.42	22.88	
1919	6.18	24.29	−.02	+2.86	0	8.17		.06
1920	7.97	24.20	+1.77	+2.77	3.13	7.67	4.90	
1921	6.91	20.79	+.71	−.64	.50	.41		.45
1922	6.84	22.23	+.64	+.80	.41	.64	.51	
1923	6.23	20.06	+.03	−1.37	0	1.88		.04
1924	6.95	23.37	+.75	+1.94	.56	3.76	1.46	
1925	4.15	17.32	−2.05	−4.11	4.20	16.89	8.43	
Mean	6.20	21.43			2.50	11.355	69.40	.99
							−.99	
							+68.41	

$(2.50)^{\frac{1}{2}}=1.58=\sigma_x$ $\quad r_{xy}=\frac{+68.41}{14\times1.58\times3.37}=+0.9174$

$(11.355)^{\frac{1}{2}}=3.370=\sigma_y$ $\quad b_{xy}=\frac{0.9174\times1.58}{3.37}=0.430$

$b_{yx}=\frac{0.9174\times3.37}{1.58}=1.955$

Regression equations:
(I) Run-off = 0.43 × rainfall − 3.01.
(II) Rainfall = 1.955 × run-off + 9.31.

CONCLUSIONS

The subject matter discussed is the result of special study, in the search of a better understanding of the problem. Having constant use for rainfall and run-off data, the writer has felt that the work of previous investigators has carried a solution only part way. It is contended that their difficulty has lain partly in the fact that the nature of the lag of run-off behind rainfall has not been sufficiently considered. A higher state of agreement seems to result, in every case that has been tried by the writer, *when* some lag is given to the run-off. The amount of this lag, as given in the examples cited, may be open to greater refinement and may be derived by more elegant methods. It may be given different values and still not vary the average results of computed values very much. For example, in the case of the Yadkin River, the lag of four months was adopted and the correlation coefficient found, considering the years 1903 to 1909, inclusive, and the year 1912. The coefficient was +0.8988. If now, in addition to the years above, we take the years 1914 to 1919, inclusive, making 14 years in all, and take a lag of 2½ months only, the correlation coefficient comes out at +0.9061 (about the same figure, although slightly higher); and the computed results differ very little from those in Table 3 (the average). However, if *no* lag is given the run-off, the correlation is very small.

Variation in temperature and wind movement must have considerable effect upon the amount of rainfall that is responsible for the mainstay of the stream's flow. Attempts to include consideration of these factors in the Wagon Wheel Gap data have led nowhere up to the present. Run-off seems to be roughly inversely proportional to wind movement and temperature, and these two latter variables display considerable change in value in the Wagon Wheel Gap data. Their influence may be the missing link of some 11 to 12 per cent that we seem to lack in the correlation coefficient. It is the hope of the writer that this article may provoke further study leading to a complete and elegant solution.

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RAINFALL PERSISTENCY AT SAN JUAN, P. R.

By C. L. RAY

[Weather Bureau, San Juan, P. R., April 22, 1929]

The following notes relating to rainfall persistency at San Juan, P. R. were suggested by an original study of Besson, an abstract of which appeared in the MONTHLY WEATHER REVIEW, June, 1924, page 308,[1] "On the Probability of Rain (at Montsouris near Paris)." The factor of persistency or the tendency of rainfall to repeat itself for 1, 2, 3, or a greater number of consecutive days, was found to be markedly higher than the general probability, or in other words, the probability independent of what took place the day before. For example, at Monsouris the general probability for rain is 0.525. In a 50-year record there were 9,580 rainy days out of a possible 18,261, while there is an increase of 18 per cent or to 0.704 in the probability of a continuation of rain on a second day. There is also a gradual increase in the probability up to and including 15 days of rain and except for a short lapse a further increase for the higher groups. A similar study by Blair[1] based upon 30 years' records at Lincoln, Nebr., shows much the same effect of the persistency factor. At this station a general probability of 0.394—4,312 days of rain out of 10,956 possible is followed by an increase to 0.540 for a second day, or 14 per cent, and a gradual rise in values in consonance with the increase of consecutive days of rain.

In the present paper we have taken as a basis the 29-year-record at San Juan, P. R., comprising 6,205 rainy days out of 10,585 possible, for a general probability of 0.586. In Table 1 are given the total of single or separated days of rain, and the number of groups of 2, 3, 4, 5, etc., consecutive days upon which precipitation occurred. In the same table is shown the calculated days of rain (the number that would be expected) derived from the equation of general probability. The actual cases with rain exceed the calculated where more than 5 days are considered but are less where 1, 2, 3, 4, or 5 days is the factor. Thus we have a first indication of the part played by a markedly long series of daily showers at San Juan, which as

[1] Besson: Vol. 52, Mo. Wea. Rev., p. 309. Blair: Vol. 52, Mo. Wea. Rev., p. 350.

a rule are of short duration though commonly at an excessive rate. Of the total of rainy days nearly 67 per cent occur in groups of 5 days or more with 2 cases of exceptional length, the one with 25 days consecutive days and the other with 44 days, exceeding the Biblical 40 days and 40 nights, though in the present instance nocturnal precipitation is of generally greater frequency during at least 9 months of the year, including the fall and winter period in which the 44-day record occurred.

From data in Table 1 we compute the probability of rain where it is known to have rained the day before, using the equation in which S equals the number of groups of consecutive rainy days, K, and n the total number of rainy days, to solve for P, the probability of rain after K days. As shown in Table 2 the probability after one day of rain is 0.687 as compared with the general probability of 0.585, or an increase of 10 per cent, after 2 days, 0.705, after 3 days 0.718, etc. The results are in general, in close agreement with values at Montsouris and at Lincoln except for the somewhat lower probabilities at the latter station.

TABLE 1.—*The number (S) groups of (k) consecutive rainy days, San Juan, P. R.*

k	1	2	3	4	5	6	7	8	9	10	11	12
S, observed	684	410	253	170	120	89	69	34	32	16	17	41
S, calculated	1,061	623	365	214	125	75	42	25	15	9	5	3
k	13	14	15	16	17	18	19	20	21	22	23	24
S, observed	11	4	4	2	3	3	1	1	1	2	1	0
S, calculated	2	1	0.7	0.4	0.2	0.1	0.08	0.04	----	----	----	----

Also 1 group of 25 days and 1 group of 44 days.

TABLE 2.—*Probability (Pk) of rain when it is known to have rained the (k) preceding day, San Juan, P. R.*

k	Pk	k	Pk	k	Pk	k	Pk
1	0.689	12	0.771	23	0.90	34	0.90
2	.705	13	.79	24	.90	35	.90
3	.718	14	.82	25	.90	36	.90
4	.724	15	.82	26	.90	37	.90
5	.728	16	.82	27	.90	38	.90
6	.732	17	.81	28	.90	39	.80
7	.740	18	.82	29	.90	40	.80
8	.761	19	.85	30	.90	41	.80
9	.759	20	.85	31	.90	42	.70
10	.772	21	.85	32	.90	43	.50
11	.764	22	.86	33	.90	------	------

In Table 3 is the coefficient of persistency for the several months, and year. The ratio: $-R=\frac{P'-P}{1-P}$ is used where P is the general probability, P' the probability after one day of rain. In solving, R would equal 0 if there were no influence from rain the day before and equal to 1 if the rain of the preceding day assures another rain. From the values derived we obtain an indication of the relative influence of persistence in the several months and seasons. The most marked effect from this factor is shown for the month of March with the value 0.35 as compared with 0.08 for July. Thus in March the probability for a second day of rain is 18 per cent greater than the general probability, while in July the difference is negligible, being but 2 per cent. Secondary maxima of 0.34 and 0.32 occur in November and May, respectively, in consonance with a 12 to 15 per cent difference between the general probability and the probability after one day of rain. In the months of June, July, and August we find there is the least effect from persistency, especially marked in July when it is but one-fourth of the March, May, and November values. To trace the cause of this variance it is indicated in large measure by the absence of temperature contrasts during the summer period and the more local character of the precipitation. At Lincoln the coefficiency values also reveal a minimum influence during the summer period. At Montsouris the differences between the several months are less although the highest values occur in May, February, and November, very nearly the same grouping as at San Juan.

TABLE 3.—*Monthly and annual values of the coefficient of persistency R*

SAN JUAN, P. R.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
P	0.640	0.524	0.487	0.475	0.536	0.568	0.661	0.607	0.587	0.604	0.633	0.700	0.586
P'	.718	.654	.664	.578	.683	.640	.689	.672	.665	.694	.757	.773	.687
R	.22	.26	.35	.20	.32	.17	.08	.17	.19	.23	.34	.24	.24

MONTSOURIS

P	0.582	0.558	0.551	0.530	0.499	0.476	0.470	0.456	0.452	0.529	0.574	0.618	0.525
P'	.708	.760	.713	.693	.742	.650	.679	.641	.649	.688	.762	.767	.704
R	.30	.46	.36	.35	.49	.33	.39	.34	.36	.34	.44	.39	.38

LINCOLN

P	0.37	0.38	0.37	0.48	0.49	0.50	0.42	0.42	0.38	0.33	0.29	0.30	0.394
P'	.52	.56	.52	.60	.60	.59	.50	.46	.53	.54	.52	.31	.540
R	.24	.29	.24	.23	.22	.18	.14	0.7	.24	.31	.32	.30	.241

In summarizing, it is found that the probability of rain at San Juan is definitely influenced by the weather of the preceding day, that this influence is found to persist for a considerable period without break and that given a longer period of observations it seems justifiable to assume that the probability will continue a gradual increase throughout. It is found also that there is some variation in the effect of persistency as regards the several months and seasons and it is indicated that this difference is largely dependent upon local climatic characteristics, with a generally minimum value occurring during the summer period of slight temperature contrasts and the frequently local type of rainfall.

FLOOD PREDICTIONS FROM STORM PATHS, PREFLOOD RIVER STAGES, PRECIPITATION DATA, AND PEAK RIVER STAGES[1]

JAMES E. STEWART and E. T. SCHULEEN

[West Virginia Power & Transmission Co., Pittsburgh, Pa., March 14, 1929]

This paper outlines a working method of making flood predictions from storm paths, preflood river stages, precipitation data, and peak river stages. The study is confined to flood predictions for the Lake Lynn Hydro-Electric Plant,[2] but the method can be applied to future run-of-river hydroelectric plants in Cheat Basin. (See fig. 1.) Also it is believed that the method can be used in developing flood prediction systems for other Appalachian drainage systems.

At the Lake Lynn plant there is an occasional heavy flood water wastage which might be reduced by utilizing stored water ahead of the floods and storing water during the floods. Manifestly, such a method of storage manipulation is not feasible without an accurate flood warning system—a system for which any flood warning would be available long enough before the arrival of the flood peak at the Lake Lynn plant to permit the desired plant usage of preflood stored water, of which about 30,000 acre feet, with 18½ feet draw down of the pond, is economically available for use.

A study of past floods indicates that the United States Weather Bureau's accurate system of flood warnings, based on an upstream peak stage method of prediction, will not give enough warning time to be of material benefit in operating run-of-river hydroelectric plants located on short, steep-sloped rivers. This is due to the fact that warnings of the rapidly moving crest stages would not be available much, if any, before the floods reached the point for which the predictions were made. Accordingly, a Cheat River flood prediction system, based on a new method, has been developed which, by virtue of accuracy and warning time, will permit a safer utilization of preflood stored water than has been possible in the past. The new method of flood prediction is based on storm paths, preflood stages for Cheat River, storm precipitation for selected Weather Bureau stations southwest of Cheat Basin, storm precipitation for Cheat Basin, and upstream peak river stages for Cheat River.

In making the flood prediction study, it was necessary, of course, to make a study of past records of floods, storms, and precipitation. For this flood study and future prediction work, it was found that the flood records for Rowlesburg, 40 miles upstream from the Lake Lynn plant, would give the most satisfactory results. Rowlesburg gage readings were started in 1884, but accurate readings at all stages were not available until after a Mott tape gage was installed July 19, 1912, and correctly read starting about October 11, 1912. The record from October 1, 1912, to December 31, 1928, has been utilized in this study.

The time and peak stages of the Rowlesburg flood as well as the preflood stages, prior to November 18, 1923, were obtained from graphs drawn from the regular twice daily gage-height readings, augmented by many special peak readings. An automatic water-stage recorder was installed on November 18, 1923, and data for floods after that date were taken from its record.

The greatest Cheat River discharge that normally can be handled without flood warning and without spillage at the Lake Lynn plant has been taken as the dividing line between floods and nonfloods. This discharge is about 8 second-feet per square mile, or 8,000 second-feet at Rowlesburg and 11,500 second-feet at Lake Lynn.

The study that was necessary, not only in developing the new method but also in working out a Cheat River flood prediction system from the method, involved the consideration of all possible flood factors. Analyses of the immediate Cheat River flood factors indicated that they are as follows: (1) Ground storage capacity, of which river stage is an inverse index; (2) rate of release of water to the river in the form of liquid precipitation or melted snow; (3) basin distribution of the total released water; (4) direction and rate of travel of the rainstorm when present.

It was considered justifiable to disregard items (3) and (4) above, because the basin rainfall distribution and the direction and rate of storm travel are fairly uniform for the storms under consideration.

A measure of the available ground storage capacity prior to a flood was determined from the Rowlesburg preflood stage, i. e., the lower the stage the greater the available ground storage, and the higher the stage the less the available ground storage (up to complete soil saturation). The preflood stage was taken from the Rowlesburg flood hydrographs, which were extended backward far enough to obtain the minimum stage that occurred prior to the flood peak (ordinarily from 12 to 24 hours before, and never more than 72 hours before the occurrence of the flood peak).

The rate of release of water to the river in the form of precipitation was determined from the average 48-hour precipitations recorded at Elkins, Rowlesburg, and Davis, W. Va. The 48-hour average includes the maximum published 24-hour average plus the amount recorded for the previous 24 hours, an arrangement which apparently gives the best definition between floods and nonfloods.

The rate of release of water to the river in the form of melted snow is a difficult quantity to determine. It depends on the amount of snow on the ground, the temperature, and the amount of rainfall. Good judgment is essential to a proper interpretation of these factors.

The precipitation over Cheat Basin is normally the greatest flood factor. It may be the result of local rains and thunderstorms, or it may come from well-defined cyclonic disturbances that pass over or near the basin. Analyses of past basin records indicate that the latter type of storm was the major cause of flood precipitation, and, accordingly, a study of all cyclonic movements since October, 1912, was made.

The origins and paths of storms that caused floods at Rowlesburg in the past were taken from the charts published in the United States MONTHLY WEATHER REVIEW. The storm origins as set forth by Messrs. Bowie and Weightman in Types of Storms of the United States and Their Average Movements (Supplement No. 1, MONTHLY WEATHER REVIEW) were tried for this study, but after careful investigation, new storm origin areas were laid out and named northern, western, Gulf, central, and Atlantic coast. (Fig. 2.) These names apply not only to the origin areas adopted, but also to the storms

[1] This paper is essentially a condensation of one presented at the twenty-first annual convention of the Pennsylvania Electric Association at Bedford Springs, Pa., Sept. 5–7, 1928. However, an additional year of data has been utilized and the previously used data thoroughly reviewed.

[2] Located in West Virginia, 3½ miles upstream from the mouth of Cheat River. Constructed in 1925 and 1926 by Sanderson and Porter; owned by West Penn Power Co.; and operated by West Virginia Power & Transmission Co., a subsidiary of the West Penn Power Co.

themselves and their paths. (See figs. 3 and 4.) The paths for all flood storms, segregated by months, were traced according to the adopted classification. Figure 3, showing all the March western type of flood storms, illustrates the procedure that was followed, and Table 1 is a summary of the results obtained from this classification.

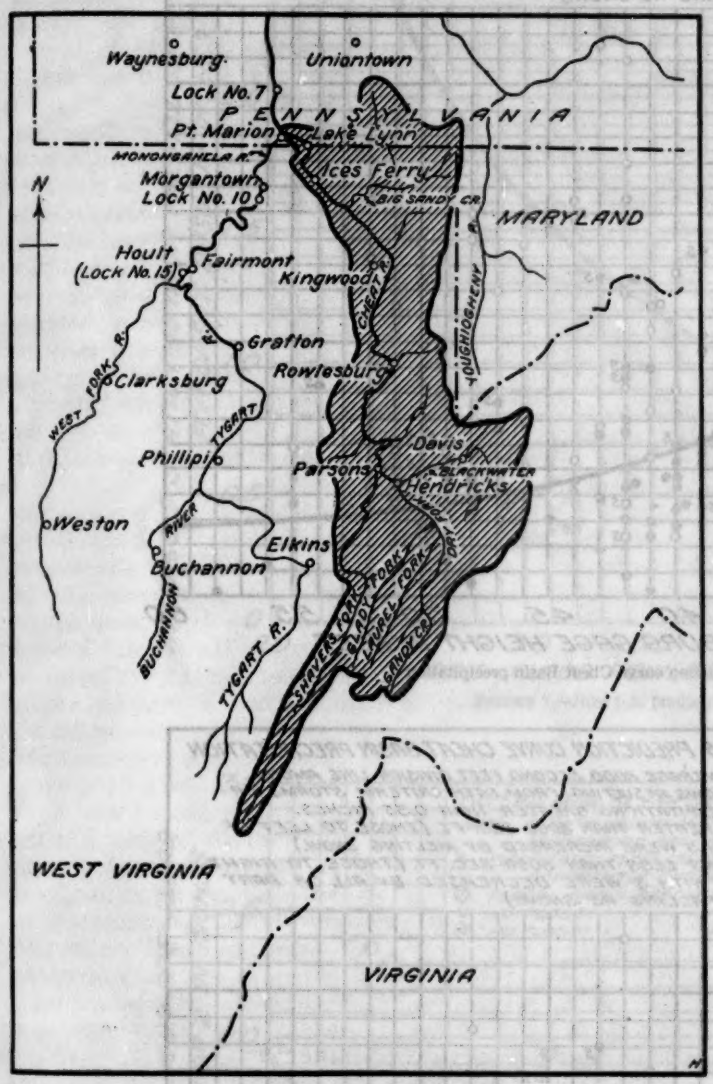

FIGURE 1.—Cheat River watershed

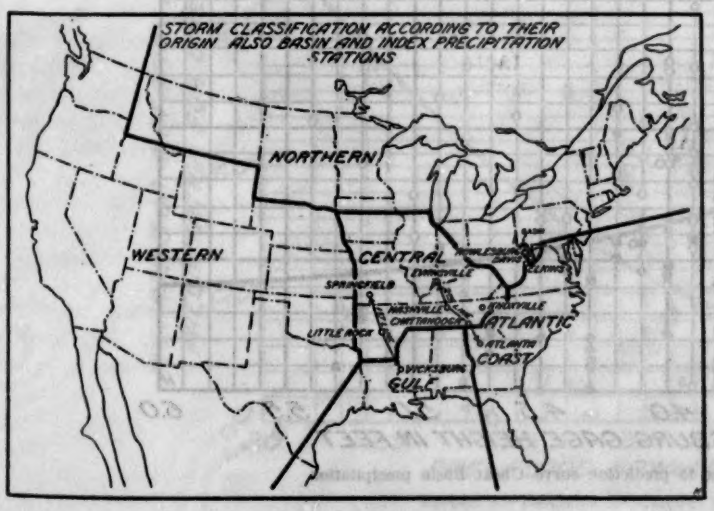

FIGURE 2.—Geographic districts

TABLE 1.—*Flood storms (flows greater than 8,000 second-feet), October 1, 1912–December 31, 1928*

Month	Atlantic coast	Gulf	Central	Western	Northern	No storm	Total
October	1	4	2	7	0	1	15
November	2	3	2	10	0	0	17
December 1–15	0	1	2	7	0	1	11
December 16–31	0	3	0	12	1	1	17
January	2	9	1	21	1	3	37
February	0	5	0	19	3	4	31
March	2	3	3	17	6	4	35
April	2	7	0	7	3	4	23
May	3	1	0	11	5	2	22
June 1–15	0	0	0	3	1	0	4
Total	12	36	10	114	20	20	212
June 16–30	0	0	0	3	0	1	4
July	0	0	1	4	2	2	9
August	0	0	1	2	1	4	8
September	1	0	0	0	2	1	4
Total	1	0	2	9	5	8	25
Total for year	13	36	12	123	25	28	237

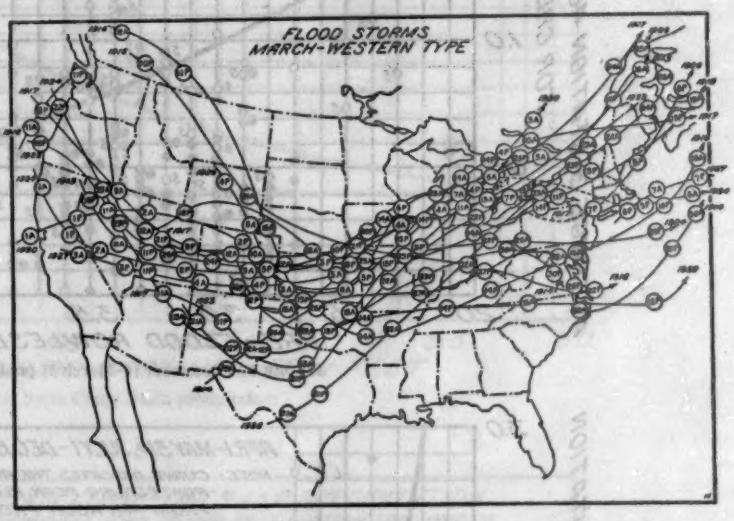

FIGURE 3.—March western type flood storm paths

A thorough investigation of the flood storms indicated that, due to their general poor flood-producing qualities, the northern type storms should be omitted from any

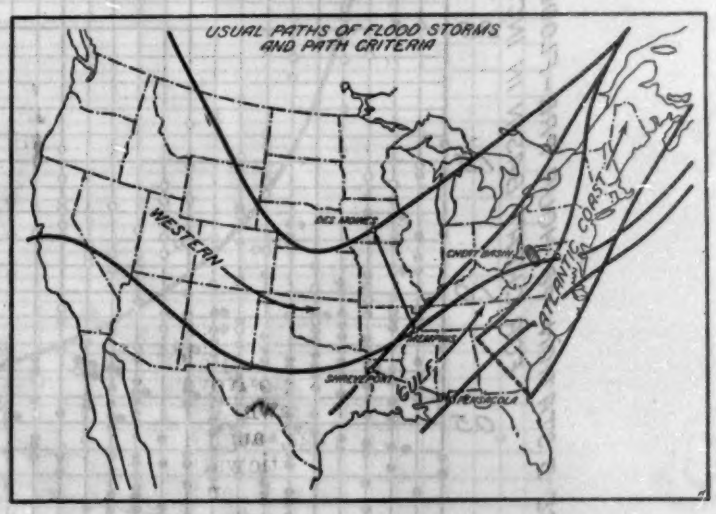

FIGURE 4.—Idealized storm paths

flood prediction plan. The investigation also led to the establishment of the following rules and path criteria for the remaining four types of storms. (Also see fig. 4.)

a. Atlantic coast type storms must originate on land to be considered possible flood makers.

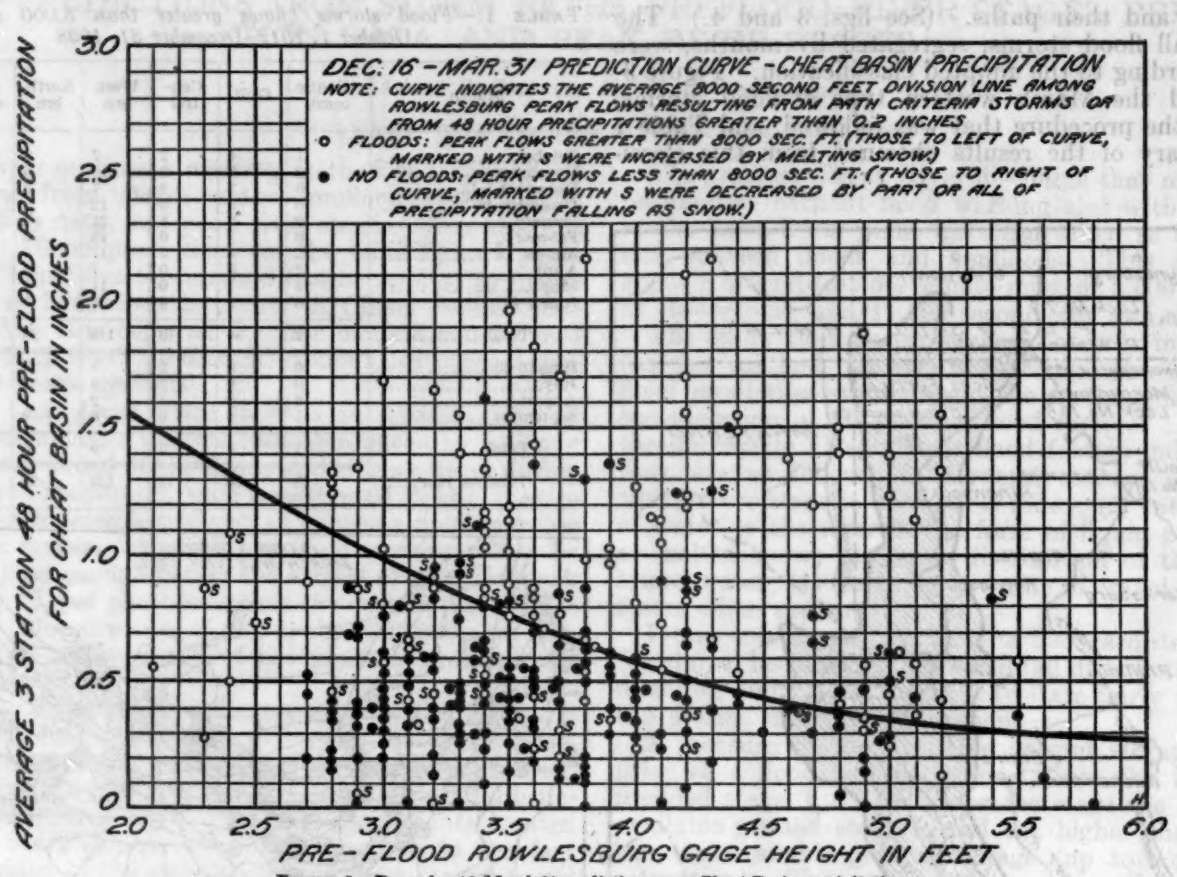
DEC. 16 - MAR. 31 PREDICTION CURVE - CHEAT BASIN PRECIPITATION
NOTE: CURVE INDICATES THE AVERAGE 8000 SECOND FEET DIVISION LINE AMONG ROWLESBURG PEAK FLOWS RESULTING FROM PATH CRITERIA STORMS OR FROM 48 HOUR PRECIPITATIONS GREATER THAN 0.2 INCHES
o FLOODS: PEAK FLOWS GREATER THAN 8000 SEC. FT. (THOSE TO LEFT OF CURVE, MARKED WITH S WERE INCREASED BY MELTING SNOW)
• NO FLOODS: PEAK FLOWS LESS THAN 8000 SEC. FT. (THOSE TO RIGHT OF CURVE, MARKED WITH S WERE DECREASED BY PART OR ALL OF PRECIPITATION FALLING AS SNOW.)
AVERAGE 3 STATION 48 HOUR PRE-FLOOD PRECIPITATION FOR CHEAT BASIN IN INCHES
3.0
2.5
2.0
1.5
1.0
0.5
0
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
PRE-FLOOD ROWLESBURG GAGE HEIGHT IN FEET

FIGURE 5.—December 16–March 31 prediction curve Cheat Basin precipitation

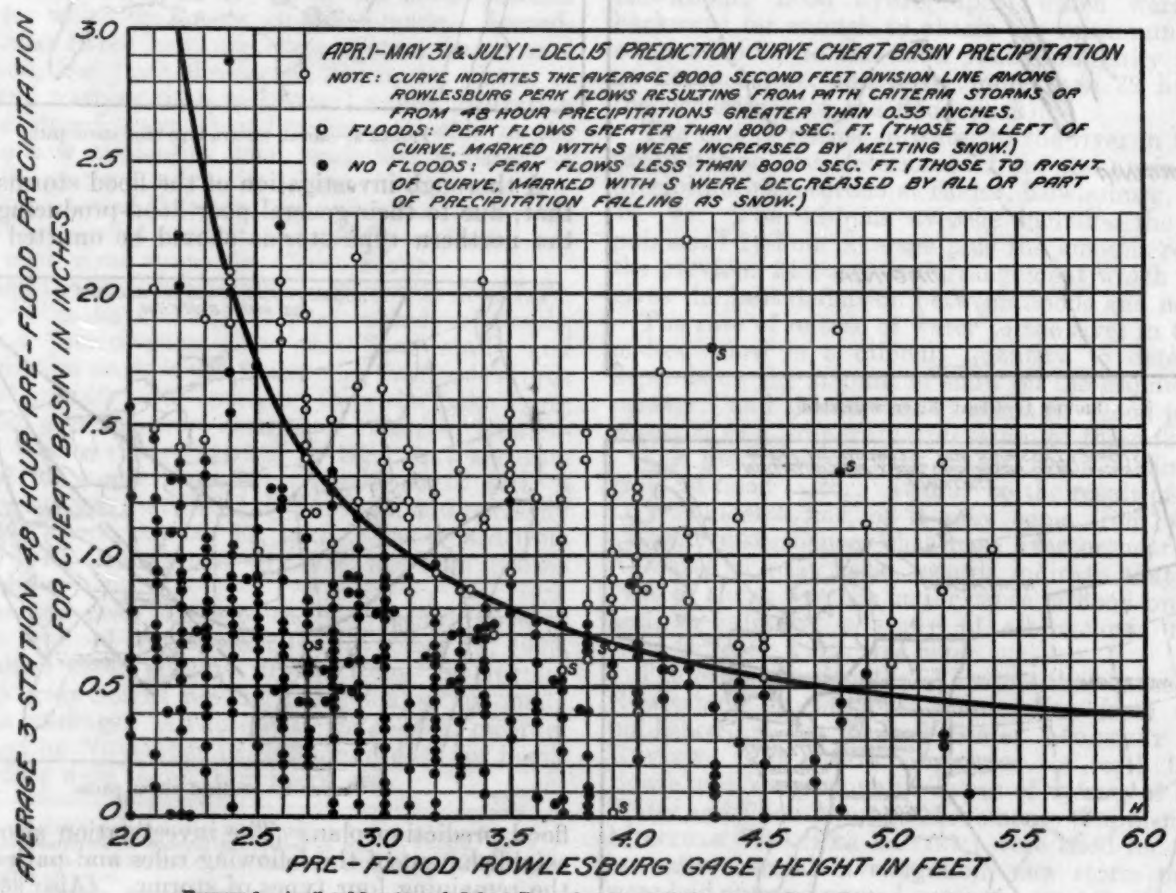
APR. 1 - MAY 31 & JULY 1 - DEC. 15 PREDICTION CURVE CHEAT BASIN PRECIPITATION
NOTE: CURVE INDICATES THE AVERAGE 8000 SECOND FEET DIVISION LINE AMONG ROWLESBURG PEAK FLOWS RESULTING FROM PATH CRITERIA STORMS OR FROM 48 HOUR PRECIPITATIONS GREATER THAN 0.35 INCHES.
o FLOODS: PEAK FLOWS GREATER THAN 8000 SEC. FT. (THOSE TO LEFT OF CURVE, MARKED WITH S WERE INCREASED BY MELTING SNOW.)
• NO FLOODS: PEAK FLOWS LESS THAN 8000 SEC. FT. (THOSE TO RIGHT OF CURVE, MARKED WITH S WERE DECREASED BY ALL OR PART OF PRECIPITATION FALLING AS SNOW.)
AVERAGE 3 STATION 48 HOUR PRE-FLOOD PRECIPITATION FOR CHEAT BASIN IN INCHES
3.0
2.5
2.0
1.5
1.0
0.5
0
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
PRE-FLOOD ROWLESBURG GAGE HEIGHT IN FEET

FIGURE 6.—April 1–May 31 and July 1–December 15 prediction curve Cheat Basin precipitation

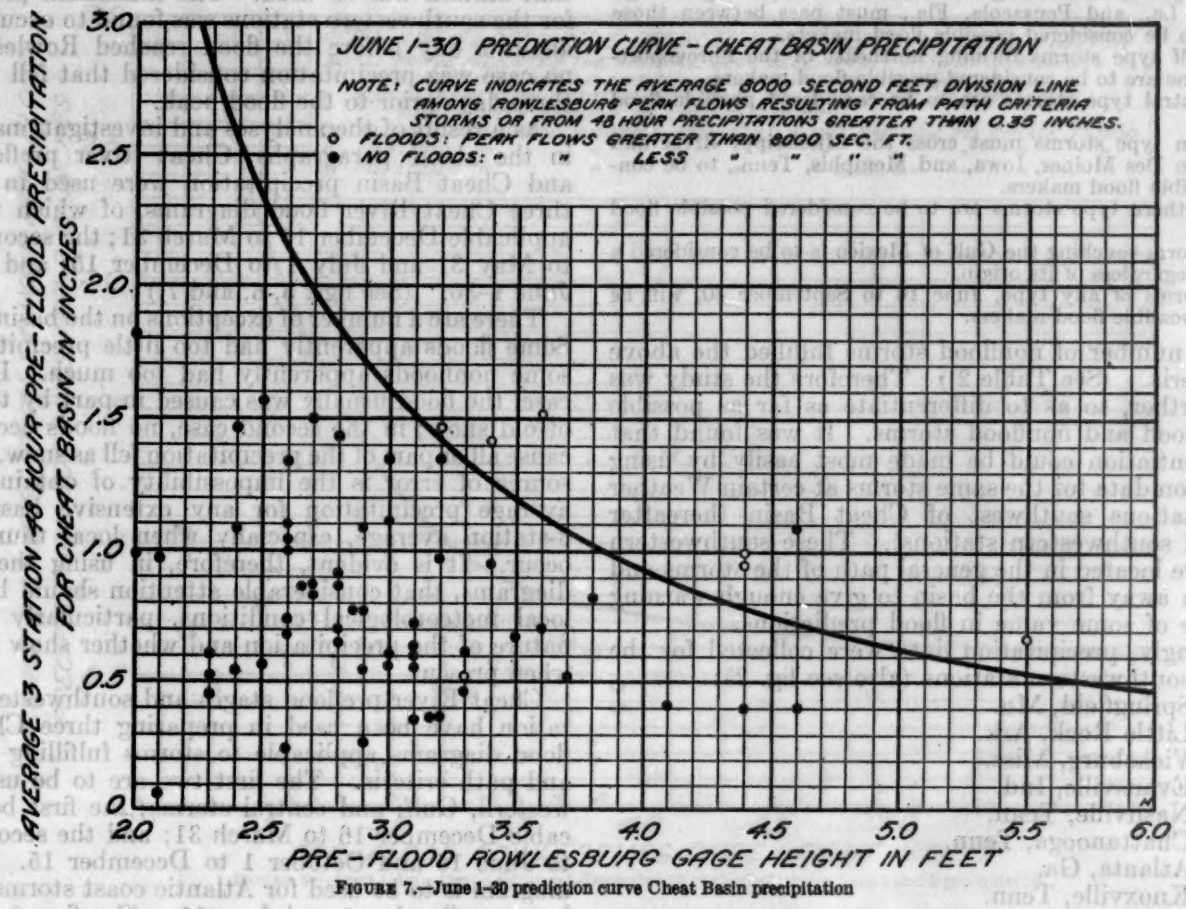
JUNE 1-30 PREDICTION CURVE - CHEAT BASIN PRECIPITATION
NOTE: CURVE INDICATES THE AVERAGE 8000 SECOND FEET DIVISION LINE AMONG ROWLESBURG PEAK FLOWS RESULTING FROM PATH CRITERIA STORMS OR FROM 48 HOUR PRECIPITATIONS GREATER THAN 0.35 INCHES.
FLOODS: PEAK FLOWS GREATER THAN 8000 SEC. FT.
NO FLOODS: " " LESS " " " "
AVERAGE 3 STATION 48 HOUR PRE-FLOOD PRECIPITATION FOR CHEAT BASIN IN INCHES
3.0
2.5
2.0
1.5
1.0
0.5
0
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
PRE-FLOOD ROWLESBURG GAGE HEIGHT IN FEET

FIGURE 7.—June 1-30 prediction curve Cheat Basin precipitation

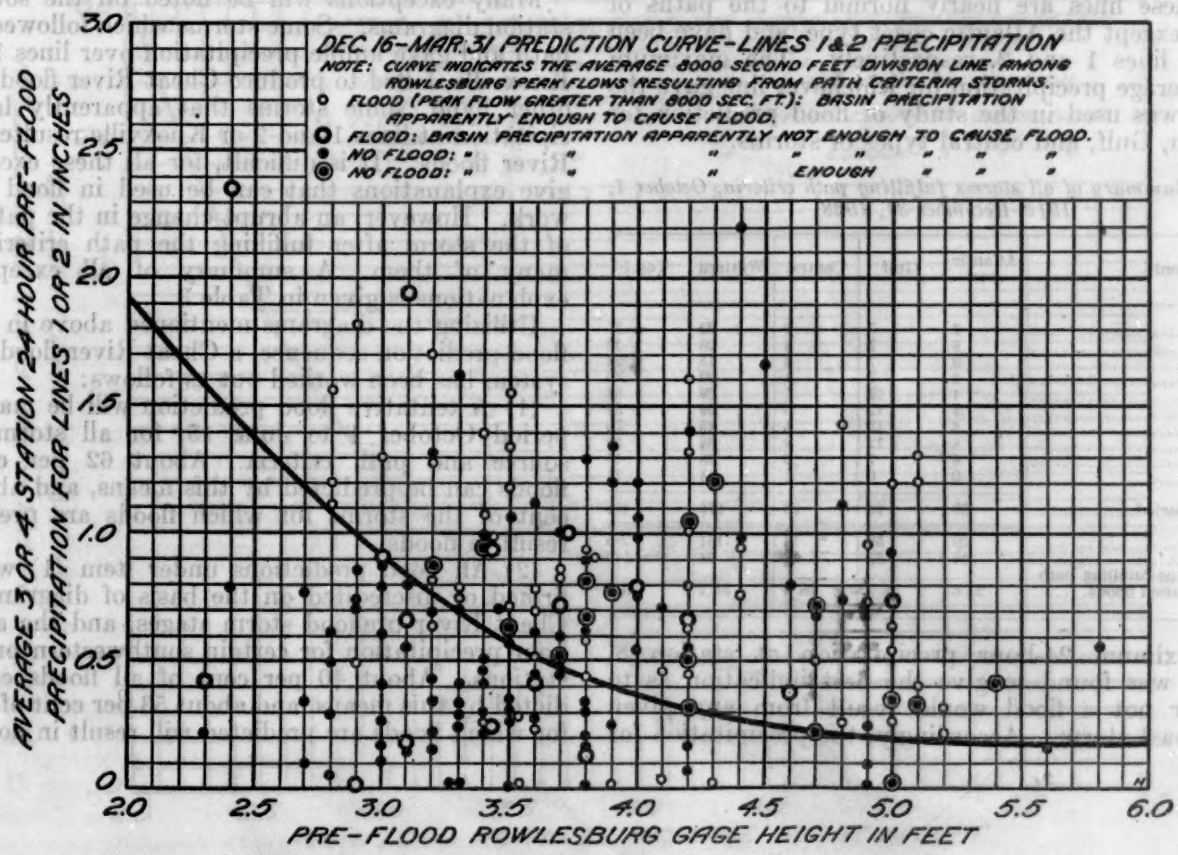
DEC. 16-MAR. 31 PREDICTION CURVE-LINES 1&2 PPECIPITATION
NOTE: CURVE INDICATES THE AVERAGE 8000 SECOND FEET DIVISION LINE AMONG ROWLESBURG PEAK FLOWS RESULTING FROM PATH CRITERIA STORMS.
FLOOD (PEAK FLOW GREATER THAN 8000 SEC. FT.): BASIN PRECIPITATION APPARENTLY ENOUGH TO CAUSE FLOOD.
FLOOD: BASIN PRECIPITATION APPARENTLY NOT ENOUGH TO CAUSE FLOOD.
NO FLOOD: " " " " " " " "
NO FLOOD: " " " ENOUGH " " "
AVERAGE 3 OR 4 STATION 24 HOUR PRE-FLOOD PRECIPITATION FOR LINES 1 OR 2 IN INCHES
3.0
2.5
2.0
1.5
1.0
0.5
0
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
PRE-FLOOD ROWLESBURG GAGE HEIGHT IN FEET

FIGURE 8.—December 16-March 31 prediction curve, lines 1 and 2 precipitation

b. Gulf type storms forming southwest of a line passing through Shreveport, La., and Pensacola, Fla., must pass between those two cities to be considered possible flood makers.

c. All Gulf type storms forming northeast of the Shreveport-Pensacola line are to be considered possible flood makers.

d. All central type storms are to be considered possible flood makers.

e. Western type storms must cross the Mississippi River and pass between Des Moines, Iowa, and Memphis, Tenn., to be considered possible flood makers.

f. No northern type storms are to be considered possible flood makers.

g. Any storm touching the Gulf of Mexico is to be considered a Gulf type, regardless of its origin.

h. No storms of any type, June 16 to September 30, will be considered possible flood makers.

A large number of nonflood storms fulfilled the above set of criteria. (See Table 2.) Therefore the study was carried further, so as to differentiate as far as possible between flood and nonflood storms. It was found that the differentiation could be made most easily by using precipitation data for the same storms at certain Weather Bureau stations southwest of Cheat Basin (hereafter designated southwestern stations). These southwestern stations are located in the general path of the storms and far enough away from the basin to give enough warning time to be of some value in flood predictions.

Accordingly, precipitation data were collected for the following southwestern stations (also see fig. 2):

1. Springfield, Mo.
2. Little Rock, Ark.
3. Vicksburg, Miss.
4. Evansville, Ind.
5. Nashville, Tenn.
6. Chattanooga, Tenn.
7. Atlanta, Ga.
8. Knoxville, Tenn.

Stations 1–3 and 4–7 are on two lines about 350 miles apart. These lines are nearly normal to the paths of all storms except the Atlantic coast type, and have been designated lines 1 and 2, respectively. The maximum 24-hour average precipitation for whichever line gave the maximum was used in the study of flood prediction for the western, Gulf, and central types of storms.

TABLE 2.—*Summary of all storms fulfilling path criteria, October 1, 1912–December 31, 1928*

Month	Atlantic coast	Gulf	Central	Western	Total
October	2	7	6	22	37
November	8	7	4	26	45
December 1–15	0	7	4	15	26
December 16–31	2	7	1	20	30
January	4	19	1	29	53
February	3	12	0	39	54
March	6	13	6	45	70
April	8	12	1	38	59
May	6	7	2	28	43
June 1–15	0	0	1	13	14
Total for period	39	91	26	275	431
Nonflood storms	29	59	16	181	285
Flood storms	10	32	10	94	146
Per cent of storms fulfilling path criteria that caused floods	25.6	35.2	38.4	34.2	33.8

The maximum 24-hour precipitation at station 8, Knoxville, was found to give the best indication as to whether or not a flood would result from any given Atlantic coast storm. Accordingly, the precipitation for that station was so used. The maximum precipitation for the southwestern stations was found to occur generally about a day before the flood reached Rowlesburg. In no case was precipitation considered that fell more than three days prior to the flood peak.

As a result of the analyses and investigations described in the above paragraphs, Cheat River preflood stages and Cheat Basin precipitation were used in preparing three Cheat River flood diagrams, of which the first is applicable December 16 to March 31; the second, April 1 to May 31 and July 1 to December 15; and the third, June 1–30. (See figs. 5, 6, and 7.)

There are a number of exceptions on the basin diagrams. Some floods apparently had too little precipitation, and some nonfloods apparently had too much. In the first case, the flood usually was caused in part by the melting of old snow; in the second case, no floods occurred because all or part of the precipitation fell as snow. Another source of error is the impossibility of obtaining a true average precipitation for any extensive basin from a 3-station average, especially when local thunderstorms occur. It is evident, therefore, in using the foregoing diagrams, that considerable attention should be given to local meteorological conditions, particularly as to the nature of the precipitation and whether show is melting, when present.

Cheat River preflood stages and southwestern precipitation have been used in preparing three Cheat River flood diagrams applicable to storms fulfilling the source and path criteria. The first two are to be used for the western, Gulf, and central storms; the first being applicable December 16 to March 31; and the second April 1 to June 15 and October 1 to December 15. The third diagram is to be used for Atlantic coast storms occurring between October 1 and June 15. (See figs. 9 and 10.)

Many exceptions will be noted on the southwestern station diagrams. Some storms which followed the usual path and gave ample precipitation over lines 1 and 2, or Knoxville, failed to produce Cheat River floods. On the other hand, some storms that apparently lacked precipitation at lines 1 and 2 or Knoxville resulted in Cheat River floods. It is difficult, for all these exceptions, to give explanations that can be used in flood prediction work. However, an abrupt change in the path or speed of the storm after fulfilling the path criteria explains many of them. A summary of all exceptions and explanations is given in Table 3.

Utilizing the diagrams mentioned above in the proper flood-prediction sequence, a Cheat River flood-prediction system has been worked out as follows:

(1) A tentative flood prediction will be made, for the period October 1 to June 15, for all storms fulfilling source and path criteria. About 62 per cent of all floods can be predicted by this means, and about 34 per cent of the storms for which floods are predicted will result in floods.

(2) All flood predictions under item (1) will be confirmed or discredited on the basis of diagrams utilizing Cheat River preflood storm stages, and the average 24-hour precipitation for certain southwestern precipitation stations. About 40 per cent of all floods can be predicted by this means, and about 53 per cent of the storms for which floods are predicted will result in floods.

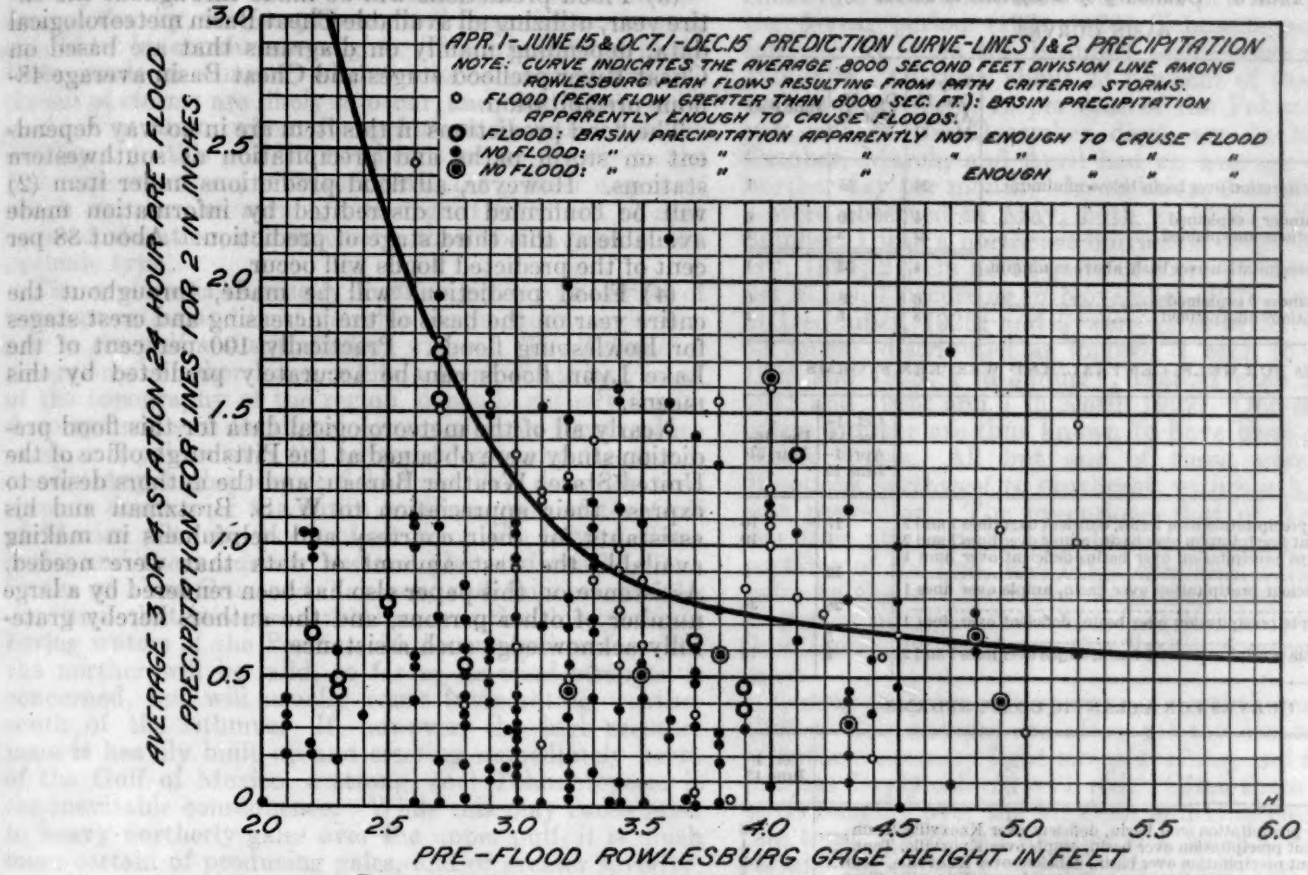
APR. 1-JUNE 15 & OCT. 1-DEC. 15 PREDICTION CURVE-LINES 1 & 2 PRECIPITATION
NOTE: CURVE INDICATES THE AVERAGE 8000 SECOND FEET DIVISION LINE AMONG ROWLESBURG PEAK FLOWS RESULTING FROM PATH CRITERIA STORMS.
FLOOD (PEAK FLOW GREATER THAN 8000 SEC. FT.): BASIN PRECIPITATION APPARENTLY ENOUGH TO CAUSE FLOODS.
FLOOD: BASIN PRECIPITATION APPARENTLY NOT ENOUGH TO CAUSE FLOOD
NO FLOOD: " " " " " " " "
NO FLOOD: " " " ENOUGH " " "
AVERAGE 3 OR 4 STATION 24 HOUR PRE-FLOOD PRECIPITATION FOR LINES 1 OR 2 IN INCHES
3.0
2.5
2.0
1.5
1.0
0.5
0
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
PRE-FLOOD ROWLESBURG GAGE HEIGHT IN FEET

FIGURE 9.—April 1–June 15 and October 1–December 15 prediction curves, lines 1 and 2 precipitation

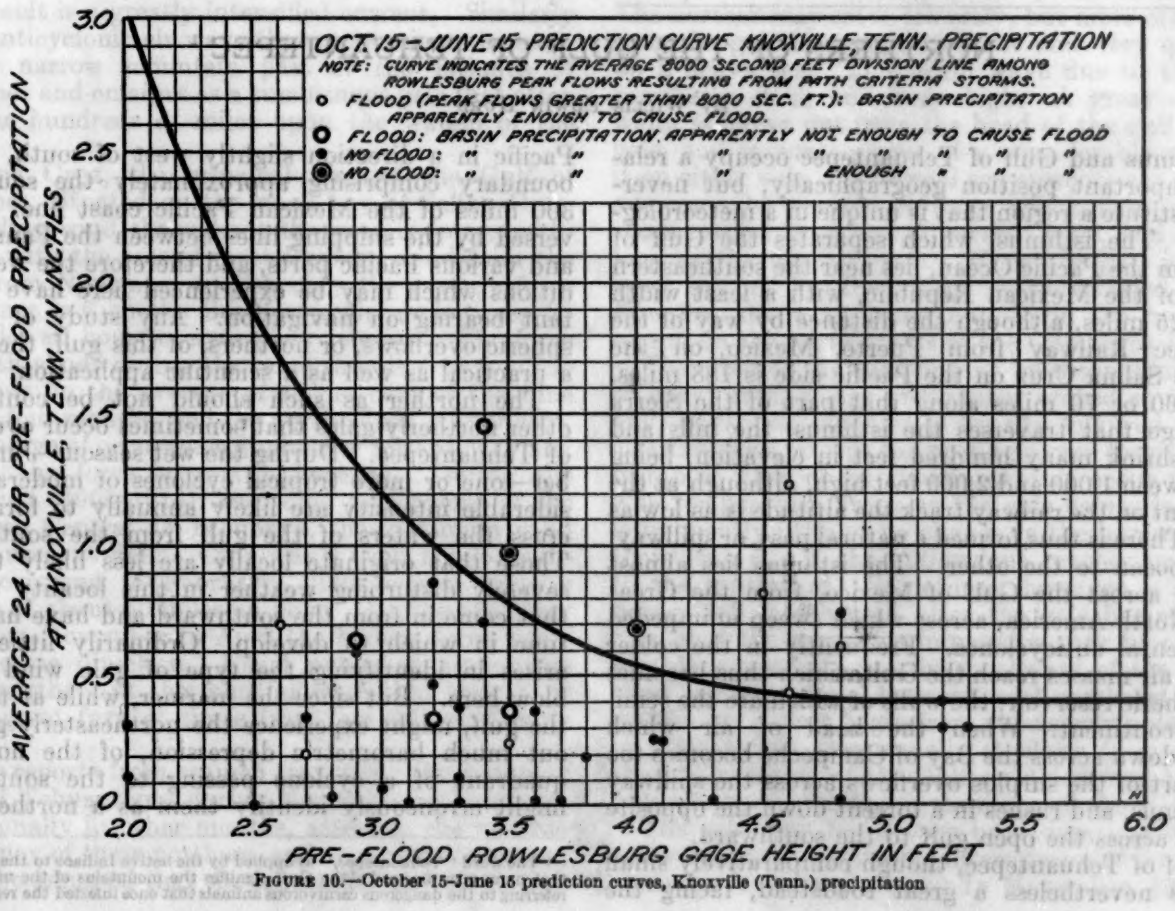
OCT. 15-JUNE 15 PREDICTION CURVE KNOXVILLE, TENN. PRECIPITATION
NOTE: CURVE INDICATES THE AVERAGE 8000 SECOND FEET DIVISION LINE AMONG ROWLESBURG PEAK FLOWS RESULTING FROM PATH CRITERIA STORMS.
FLOOD (PEAK FLOWS GREATER THAN 8000 SEC. FT.): BASIN PRECIPITATION APPARENTLY ENOUGH TO CAUSE FLOOD.
FLOOD: BASIN PRECIPITATION APPARENTLY NOT ENOUGH TO CAUSE FLOOD
NO FLOOD: " " " " " " " "
NO FLOOD: " " " ENOUGH " " "
AVERAGE 24 HOUR PRE-FLOOD PRECIPITATION AT KNOXVILLE, TENN. IN INCHES
3.0
2.5
2.0
1.5
1.0
0.5
0
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
PRE-FLOOD ROWLESBURG GAGE HEIGHT IN FEET

FIGURE 10.—October 15–June 15 prediction curves, Knoxville (Tenn.) precipitation

TABLE 3.—*Summary of exceptions to curves*

BASIN CURVES

	July 1–Dec. 15, Apr. 1–May 31	Dec. 16–Mar. 31	June 1–30
1. Floods but precipitation over basin below minimum	26	35	1
Number under 1 explained	4	30	0
Net exceptions unexplained	22	5	1
2. No floods but precipitation over basin above minimum	14	33	1
Number under 2 explained	6	28	0
Net exceptions unexplained	8	5	1

CURVES FOR GULF, CENTRAL, AND WESTERN STORMS

	Oct. 1–Dec. 15, Apr. 1–June 15	Dec. 16–Mar. 31
1. Floods, ample precipitation over basin, deficient over lines 1 and 2	17	10
2. Floods, deficient precipitation over basin, ample over lines 1 and 2	1	10
3. Floods, deficient precipitation over basin, deficient over lines 1 and 2	10	8
4. No floods, deficient precipitation over basin, ample over lines 1 and 2	28	34
5. No floods, ample precipitation over basin, deficient over lines 1 and 2	5	1
6. No floods, ample precipitation over basin, ample over lines 1 and 2	2	16

CURVES FOR ATLANTIC COAST STORMS

	Oct. 1–June 15
1. Floods, ample precipitation over basin, deficient over Knoxville, Tenn	3
2. Floods, deficient precipitation over basin, ample over Knoxville, Tenn	1
3. Floods, deficient precipitation over basin, deficient over Knoxville, Tenn	3
4. No floods, deficient precipitation over basin, ample over Knoxville, Tenn	2
5. No floods, ample precipitation over basin, deficient over Knoxville, Tenn	0
6. No floods, ample precipitation over basin, ample over Knoxville, Tenn	2

(3) Flood predictions will be made throughout the entire year, utilizing all available Cheat Basin meteorological data, depending mainly on diagrams that are based on Cheat River preflood stages and Cheat Basin average 48-hour precipitation.

The flood predictions in this item are in no way dependent on storm paths and precipitation at southwestern stations. However, all flood predictions under item (2) will be confirmed or discredited by information made available at this third stage of prediction. About 88 per cent of the predicted floods will occur.

(4) Flood predictions will be made, throughout the entire year on the basis of the increasing and crest stages for Rowlesburg floods. Practically 100 per cent of the Lake Lynn floods can be accurately predicted by this means.

Nearly all of the meteorological data for this flood prediction study were obtained at the Pittsburgh office of the United States Weather Bureau, and the authors desire to express their appreciation to W. S. Brotzman and his assistants for their courtesy and helpfulness in making available the vast amount of data that were needed. Assistance on this paper also has been rendered by a large number of other persons, and the authors hereby gratefully acknowledge such assistance.

NORTHERS OF THE GULF OF TEHUANTEPEC [1]

By WILLIS EDWIN HURD

The Isthmus and Gulf of Tehuantepec occupy a relatively unimportant position geographically, but nevertheless constitute a region that is unique in a meteorological sense. The isthmus, which separates the Gulf of Mexico from the Pacific Ocean, lies near the southeastern extremity of the Mexican Republic, with a least width of about 125 miles, although the distance by way of the Tehuantepec Railway from Puerto, Mexico, on the Atlantic to Salina Cruz on the Pacific side is 188 miles. For some 60 or 70 miles along that part of the Sierra Madre range that traverses the isthmus, the hills and highlands shrink many hundred feet in elevation, being mostly between 1,000 and 2,000 feet high, although at the highest point on the railway track the altitude is as low as 688 feet. There is thus formed a natural pass, or spillway, from one ocean to the other. The isthmus lies almost due south, across the Gulf of Mexico, from the Great Plains of North America, across which sweep unimpeded the continental anticyclones. Frequently in the colder season the air masses reach the Gulf, which thus becomes an atmospheric reservoir, the walls of which are the semi-inclosing continent. When the head of air which presses on down across the Bay of Campeche becomes too great, a part of the surplus overflows across the spillway of the isthmus, and rushes in a torrent down the opposite slopes and across the open gulf to the southward.

The Gulf of Tehuantepec, though comparatively small in area, is nevertheless a great roadstead, facing the Pacific in a direction slightly west of south, its visible boundary comprising approximately the southernmost 300 miles of the Mexican Pacific coast line. It is traversed by the shipping lines between the Panama Canal and various Pacific ports, and therefore the weather conditions which may be experienced here have an important bearing on navigation. Any study of the atmospheric overflows, or northers, of this gulf, therefore, has a practical as well as a scientific application.

The norther as such should not be confused with other northerly gales that sometimes occur over the Gulf of Tehuantepec. During the wet season—June to October—one or more tropical cyclones of moderate to considerable intensity are likely annually to form over, or cross the waters of the gulf from the southeastward. Those that originate locally are less likely to produce severely disturbing weather in this locality than those that come in from the southward and have had a longer time in which to develop. Ordinarily little confusion arises in identifying the type of gale wind that may blow here. But since the mariner, while at the head of the gulf, might experience the northeasterly gales, without much barometric depression, of the northwestern quadrant of a cyclone passing to the southward, he might erroneously identify them as a norther, unless a

[1] The word "Tehuantepec," as applied by the native Indians to the range of hills of that name near the head of the Gulf, signifies the mountains of the man-eating beasts, referring to the dangerous carnivorous animals that once infested the region.—*W. E. H.*

veering of the gale into southeasterly, an undue cloudiness of the sky, or a suspicious swell from the southward, should set his conclusions aright. This error is least likely to be made in summer, when cyclones only of the two classes of storms are likely to occur, and most likely to be made in autumn, when the cyclone and norther seasons overlap. In this gulf the norther is known locally as the Tehuantepecer, and it introduces a far greater degree of rough weather, as a rule, with regard to extent of area covered, duration, and intensity, than do the gales of the cyclonic type.

The cyclone is of wholly local origin in the region of frequent calms and light variable winds common in summer to the gulf and surrounding waters. The Tehuantepecer, on the other hand, while a local wind, by reason of the topography of the region, depends entirely for its development and continued existence upon the presence of an anticyclone over the adjacent regions to the northward. Any high-pressure field from that direction that spreads down over the entire southern part of the Gulf of Mexico piles an excess of air upon the Bay of Campeche and the bordering lowland plains of the Mexican States of Vera Cruz and Tabasco, and thus creates the condition that initiates a norther over the closely neighboring waters of the Pacific. If the anticyclone is weak, the norther will be mild, so far as its wind strength is concerned, but will usually cause invigorating weather south of the isthmus. If, however, the high-pressure mass is heavily built up and cresting immediately north of the Gulf of Mexico, a strong, cool Tehuantepecer is the inevitable consequence. While this may cause brisk to heavy northerly gales over the upper gulf, it is much more certain of producing gales, and of greater severity, over the waters of the lower gulf. The reason is clear. Pour the waters of a broad stream into a narrow gorge and the result is a greatly intensified current. Similarly with the anticyclonic air wave that presses into the comparatively narrow mountain pass of the Isthmus of Tehuantepec and emerges as a tumultuous gale that often spreads for hundreds of miles upon the waters of the Pacific.

At Salina Cruz, the principal port of the Gulf of Tehuantepec, situated on the small bay of Salina Cruz, the prevailing wind throughout the year is from north-northeast, with the second most frequent wind from the north. From November to February the average force of the former is 6 on the Beaufort scale, or between 25 and 31 miles an hour in equivalent velocity. The force of the north winds during the same time is 4 to 5. The former blows on the average of 46 per cent of the time during the four months, and the north winds, 31 per cent. The percentage of occurrence diminishes toward May and June, and the force is greatly lessened. During the 9-year period (1908–1916), according to a record of the Observatorio Central de Tacubaya, the maximum wind force measured at Salina Cruz was 9 from north-northeast and occurred in February. This was a velocity at the rate of about 50 miles an hour. During the other months from November to April the highest force was 8 from the same direction. Usual published statements upon the northers at this port indicate that they blow here with great fury at times from late fall until early spring.

Weather reports from seamen traversing the waters of the Gulf of Tehuantepec during November to February, and occasionally in other months, attest to the violence and frequency of these northers, and as regards frequency it can not be assumed that the reports for any given time constitute a complete record of their prevalence. During the 5-year period (1924–1928) Tehuantepecers of gale force—8 to 12 on the Beaufort scale—were reported on 120 days. Of these about 23 per cent of the November and January days, 15 per cent of the February, and 13 per cent of the December days, are to be included. October, March, and April had an average of 1 strong norther day per month. In addition, 2 northers of force 7 were observed in May, both in 1928. Of the whole number, 1 was a northeast hurricane, occurring in January, 1924; 2 were north gales of force 11 (64 to 75 miles per hour), 1 occurring in November, 1928, and the other in December, 1925; and 9 were gales of force 10 (55 to 63 miles), distributed as follows: 1 each in November, 1925 and 1928; 4 in January, 1928; 1 each in January, 1925 and 1926; and 1 in April, 1927. One-tenth of the entire number are thus known to have been gales of the higher forces. All but one of these were from the directions northwest to northeast, with north and northeast prevailing. The exception—that of April, 1927—was from the east. The gale field variously covered all portions of the gulf, and often extended a few hundred miles to the southward in decreasing force. In several instances moderate to whole northeasterly gales blew simultaneously far down the Pacific Central American coast.

Among the premonitory signs of norther weather in the Gulf of Tehuantepec are often a hazy atmosphere, but with the customary light airs prevailing, and sunsets and sunrises deeply colored with red. Often there are grayish mists hanging over the Mexican and Guatemalan mountain tops. In Indian weather lore, when the summits of certain high peaks are cloud-capped, the norther is expected to begin blowing on the following day, and will continue to blow as long as the peaks remain clouded. The norther may set in leisurely, but more often it drives over the gulf in a sudden burst and very quickly stirs up a heavy sea. The storm wave due to this cause is peculiarly short and very high. A great quantity of water is blown out from the head of the gulf during the gale, and in consequence of a considerable piling up of it on either side, the normal sea currents are temporarily overcome by surface currents which flow along either shore toward the place of lowered level, and continue as long as the norther lasts. When the gale is severe the swell set up by the storm is transmitted below the Equator, the wash being noticed in the height of the season on the north coasts of the Galapagos Islands.

The onset of the norther may be accompanied by light to heavy rain, as the preliminary arched squall cloud, if any, advances, but this is usually followed by quickly clearing skies, except for passing cirrus forms. In other instances little or no cloudiness may occur throughout. The temperature drops as the gale comes in, but there is frequently little or no change in the barometer, unless there is a rise if the anticyclone reaches unusually far to the southward. Sometimes, however, a slight temporary fall is observed after the gale begins, and it is then that the erroneous impression may be created that a cyclone is working to the southward of the gulf. The wind usually blows between east-northeast and west-northwest; it may begin from an easterly point and back to a westerly. Occasionally it blows from the east in the lower reaches of the Gulf, or is deflected by the coast hills into east over the western approaches.

The gale may be of very brief duration, lasting only a few hours, or, with some intermission of intensity, may continue for several days. In November, 1928, it blew

from the 20th to the 26th. In January, 1924, vessels reported that it set in on the 5th and continued until the 9th, during a part of the time rising to the force of a hurricane. In December, 1923, it came as a whole gale (force 10), though not continuously, on four consecutive days. In all these instances strongly developed and persistent high pressure conditions prevailed over the Southern States of the Union. Of all the months included in the 5-year period, January, 1928, was the stormiest, with a known record of 11 days on which winds blew with velocities of from 40 to 75 miles an hour over the Pacific gulf. In the Gulf of Mexico during the same time only one norther was reported by a vessel, and that of force 8 only.

One of the most comprehensive sea reports of norther weather ever received by the Weather Bureau was furnished through the Hydrographic Office by Capt. Arthur Cocks, master of the British steamer *Nictheroy*, San Pedro toward the Panama Canal. While west of the Gulf of Tehuantepec late on the 27th of January, 1928, the wind experienced was light southeasterly and sea oily calm. Quoting from the report:

> At 10:20 p. m. a black cloud shaped as an arch rose from the eastern horizon. At 10:45 p. m. this cloud passed over the ship; by then it had assumed the shape of a perfect curve which extended from the northern to the southern horizon, the width of the cloud being that of a rainbow, the sky otherwise being cloudless, with stars, even those at the lowest altitude, showing brightly. Soon after the cloud passed, it was seen to lose the arch formation and commence to break up into small fleecy clouds, which very quickly disappeared and the sky was again cloudless. About 10 minutes later the wind came from the ESE. at force 3, accompanied by considerable easterly swell.

Abbreviating the report: Early on the 28th the wind backed into east, then northeast by east, and was blowing a fresh gale from that direction by 8 a. m. The sunrise that morning was very red, and the temperature of the air much lower than on the preceding day. At this time a radio report from a steamer 15 miles from shore near the head of the gulf gave the wind as a whole gale from north-northeast, barometer 30.18. At 2 p. m. of the 28th the *Nictheroy* had barometer at its lowest, 30.00 inches. At 4 p. m. the air temperature was 73°, wind northeast by north, force 9, seas very heavy, sky cloudless. Ship hove to. That day "the sun set rosy red in a low haze, the sky from northeast to southwest being purple in color." Conditions were similar at sunrise of the 29th, except that the wind was now northeast in a strong gale, although the sea was decreasing. The vessel was now in the western part of the gulf, while the crest of the causing anticyclone, pressure 30.60 inches, lay over central Texas. At 8 a. m. the temperature had fallen to 68°, and the *Nictheroy* had resumed her course, but it was not until after noon that the wind, then a fresh gale from north-northeast, began rapidly to moderate, and the temperature to rise. The features of the storm which the captain desired to emphasize were (1) the unusual formation of cloud which preceded the wind; (2) the oft-repeated occurrence of three very heavy seas following in succession when the sea was roughest; (3) the moderating of the sea before the decreasing of the wind.

Although the Tehuantepecer is a norther, and probably will always retain that common name, yet it must be recognized that there is a difference between it and the norther of the Plains States and the Gulf of Mexico. The norther to the eastward of the great North American mountain system is a true anticyclonic wind, and may therefore be classified as a gradient norther. The Tehuantepecer, on the contrary, is a wind of the opposite side of the Cordillera, is ordinarily little associated with pressure changes of moment, and is primarily a mere overflow of heaped up air through a mountain pass from the lower part of the basin in which the anticyclone operates. It is, therefore, a derivative or overflow norther, and might be classified as an orographic norther. When the conditions inducing the Tehuantepecer extend sufficiently far to the southward, other overflows of lesser volume appear to occur through the passes of Central America, producing local northeasterly winds on its Pacific coast of a similar character. One of these is found exemplified in the Bay of Papagayo, on the northwest coast of Costa Rica, and is known locally as the Papagayo. The same name seems to be applied to similar winds of neighboring parts of the coast, especially those of Nicaragua and Guatemala.

METEOROLOGICAL PROGRAM OF THE SEVENTH CRUISE OF THE "CARNEGIE," 1928–1931

By CHARLES F. BROOKS, Clark University, Worcester, Mass.

The nonmagnetic ship *Carnegie* is known the world over for its magnetic surveys of all the oceans during six cruises from 1909 to 1921. Now the ship, refitted and equipped for special oceanographic and meteorological work as well as for magnetic and atmospheric-electric, is well along on its seventh cruise, one which will carry it 110,000 miles in three years. The *Carnegie* is primarily a sailing vessel of 600 tons, with hemaphrodite brigantine rig. (See fig. 1.) It has also an auxiliary motor capable of 6 knots. The crew is 17 men, and the scientific staff, including Capt. J. P. Ault, numbers 8, 2 of whom, Dr. J. H. Paul and Oscar W. Torreson, have the meteorological observations as part of their duties.

The route covered through March, 1929, and that planned for the remainder of the cruise is shown in Figure 2. The *Carnegie* alternates hemispheres to avoid winter storms. Ports of call are few and far between. Sailing from Washington, May 1, 1928, the *Carnegie* for several days checked its magnetic instruments against indications of land parties, then after a few days at Newport News made a stormy and slow 29-day passage to Plymouth. Easterly and southeasterly winds and gales held up the vessel off the entrance to the English Channel for 10 days. A fortnight each was spent at Plymouth and Hamburg for the completion of the meteorological and oceanographic equipment and for repairs to the ship after the buffeting. Dr. H. U. Sverdrup, of the Geophysical Institute in Bergen, Norway, and research associate of the Carnegie Institution, inspected the vessel and assisted in the scientific installations at Hamburg. Also, many constructive suggestions were made by members of the *Meteor* expedition. The voyage to Reykjavik, July 7 to 20, and thence to Barbados July 27 to September 17, was moderately stormy in the north, but generally quiet in the south except for two gales, one of them in the southern part of the great September hurricane. From Barbados to Panama squalls helped and calms and head-winds delayed progress. At Balboa the ship was again dry-docked and made ready for a long circuit in the South Pacific. After leaving Balboa October 25, two weeks were required to get out of the Gulf of Panama against the constant southwesterly

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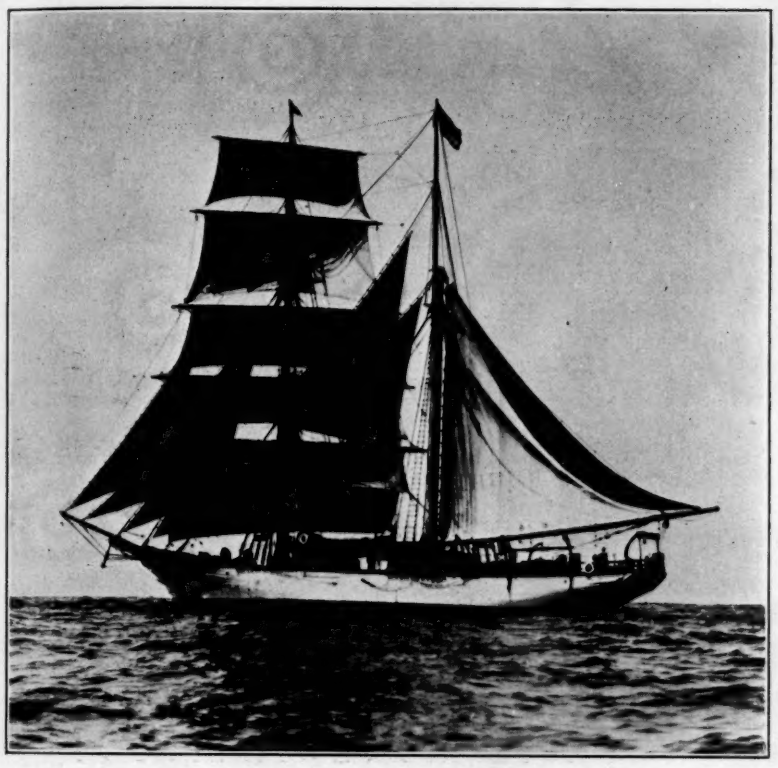

FIGURE 1.—The yacht *Carnegie* under sail January 14, 1929, in the South Pacific Ocean in latitude 2° S. and longitude 95° W.

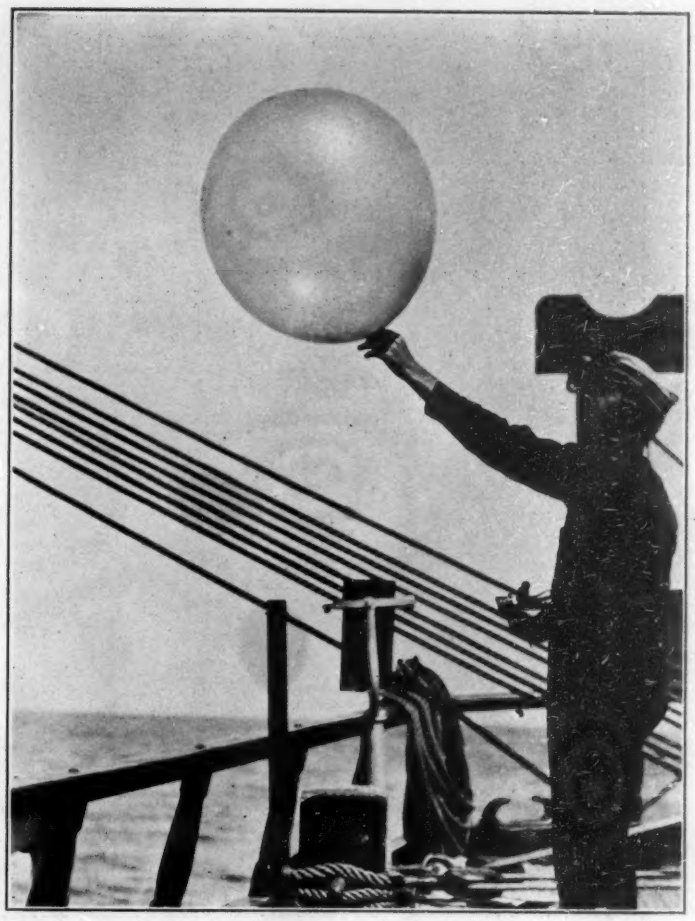

FIGURE 3.—Releasing pilot balloon on board *Carnegie*, South Pacific Ocean. Note the sextant in the observer's hand, and the rain gage on gimbals in the background

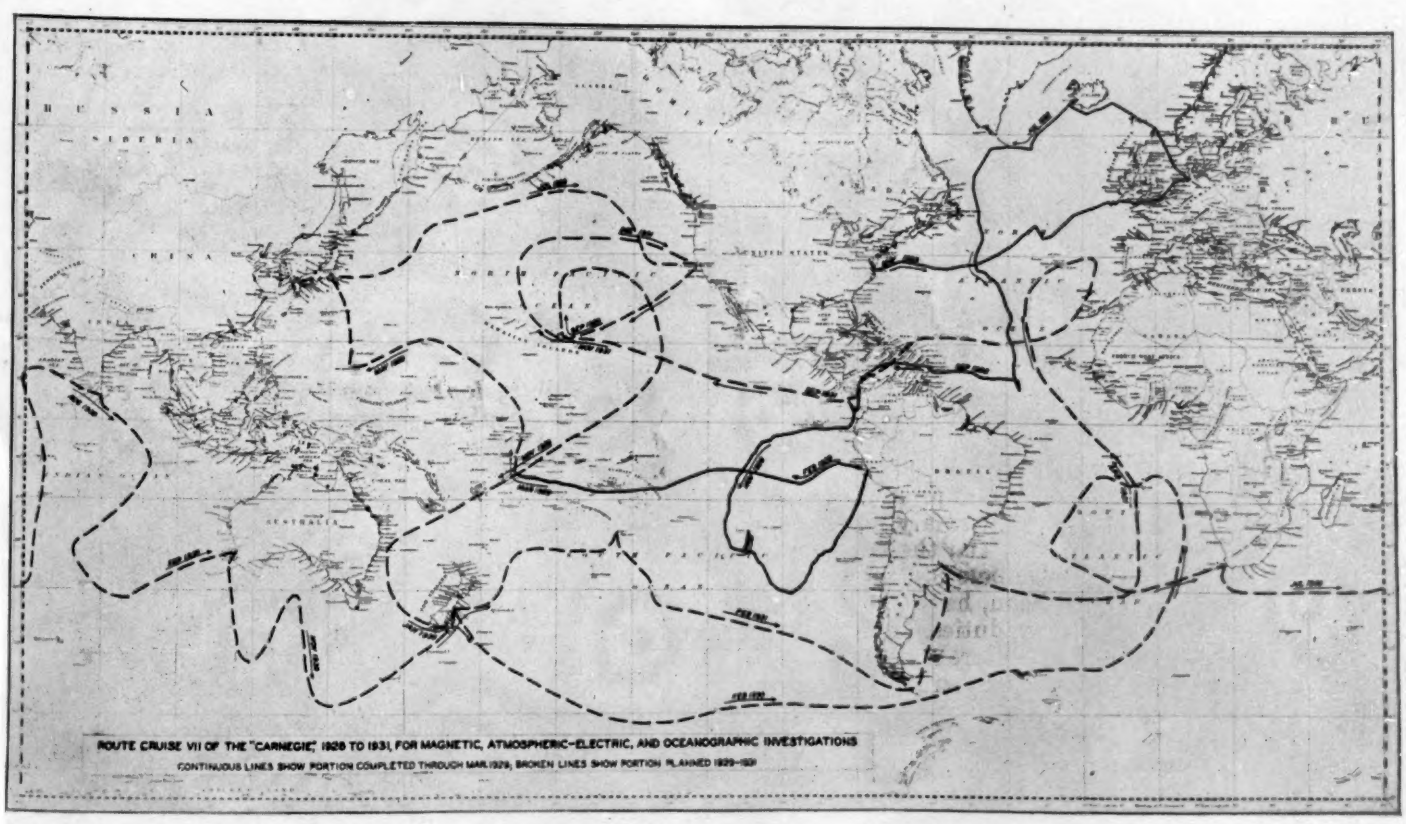
RUSSIA
SIBERIA
CHINA
ROUTE CRUISE VII OF THE "CARNEGIE," 1928 TO 1931, FOR MAGNETIC, ATMOSPHERIC-ELECTRIC, AND OCEANOGRAPHIC INVESTIGATIONS
CONTINUOUS LINES SHOW PORTION COMPLETED THROUGH MAR. 1929, BROKEN LINES SHOW PORTION PLANNED 1929-1931

FIGURE 2.—Route of the seventh cruise of the *Carnegie*

UNIV. OF MICH.

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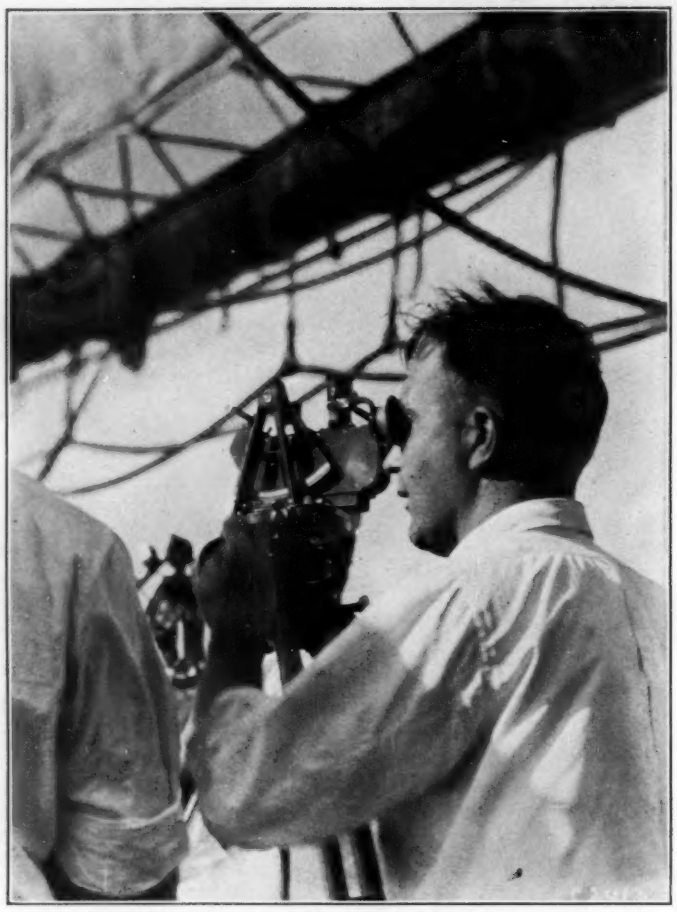

FIGURE 4.—Observing the course of a pilot balloon with the United States Navy theodolite

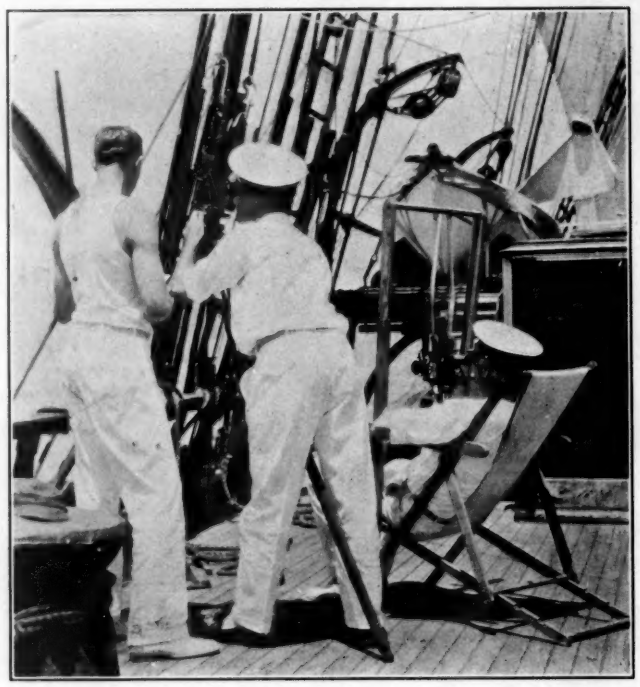

FIGURE 5.—Observing the course of a pilot balloon with theodolite and sextant. The spring supporting the sextant hangs from a screw eye in the bar over the chair

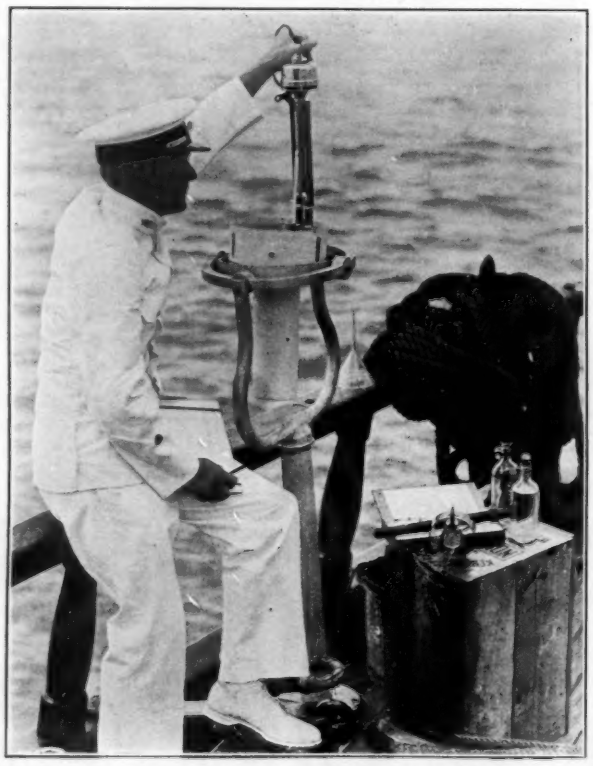

FIGURE 6.—The evaporimeter, Assmann aspiration psychrometer, surface temperature thermometer, and hand anemometer

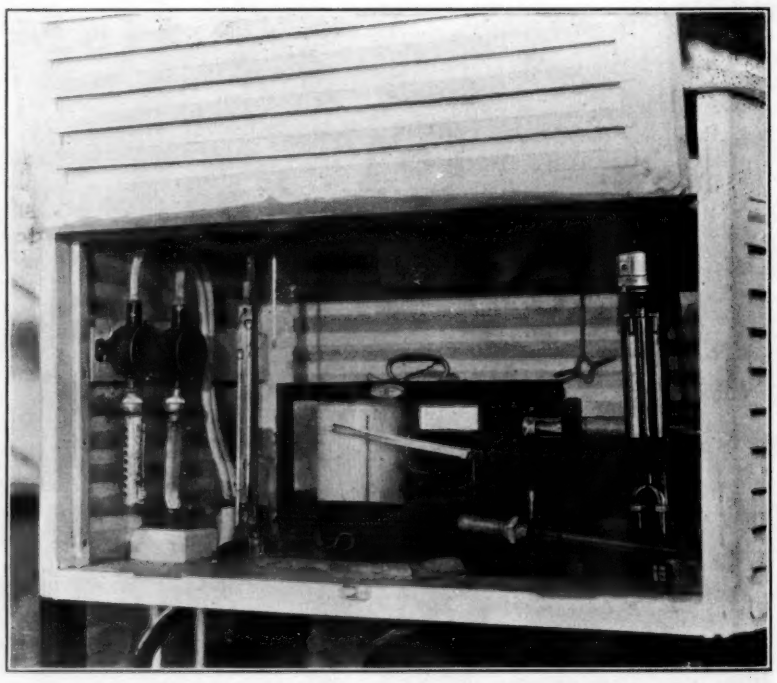

FIGURE 7.—The thermometer shelter, open. On right, wet and dry pair of Hartmann & Braun electrical resistance thermograph, and ordinary sling psychrometer. In center, Negretti & Zambra ventilated wet and dry bulb thermograph. The motor box is just visible at the extreme right, outside the shelter, while the long horizontal bulbs are to be seen at the right in the shelter. The Assmann aspiration psychrometer is at the right

winds, attended by heavy rains and squally weather. But the following two months "were featured by excellent weather, light winds, cool temperature, little rain or fog, and only one gale which continued for six hours." After touching at Easter Island and being driven 300 miles south by head-winds, the *Carnegie* made a good run to Callao, reaching there January 14, 1929.[1] Thence to its May 1 position in the tropical mid north Pacific letters from Samoa and radiograms say favorable weather continued. The expedition will stop in Japan then make San Francisco in August, where the twenty-fifth anniversary of the founding of the Department of Terrestrial Magnetism will be celebrated at that time.

An abbreviation of the magnetic and atmospheric-electric studies of previous cruises has made possible the introduction of a considerable oceanographic and meteorological program in the present cruise.[2] Continuous observations of the weather both by eye and recording instruments are being supplemented by special meteorological work to the extent permitted by the rest of the full program. Preparations commenced more than two years in advance and the experience of the recent *Meteor* expedition [3] have permitted the working out of a highly satisfactory schedule and the installation of the required instruments and apparatus.

Meteorological.—Observations made on previous cruises of the *Carnegie* have been as follows:

1. Continuous record of air temperature by thermograph in shelter on quarter-deck, checked by thermometer reading daily when thermogram was changed.

2. Continuous record of atmospheric pressure by barograph in cabin, checked by aneroid readings daily when barogram was changed, aneroid being checked by mercurial barometer readings once each day at Greenwich mean noon.

3. Greenwich mean noon observations once each day, consisting of readings of mercurial barometer, air temperature, wet and dry bulb readings for relative humidity with sling psychrometer, water temperature, wind direction and velocity (by estimation on Beaufort scale), clouds (form of, direction moving from, and amount), state of weather and of sea, with gale, storm, and for reports.

4. Hourly reports by watch officers of wind direction and velocity, and state of weather and sea.

5. Four-hour reports by watch officers of wet and dry bulb and water temperatures, and aneroid reading, in addition to hourly readings as listed under 4.

6. Special meteorological observations in connection with atmospheric-electric work consisting of hourly observations of mercurial barometer, wet and dry bulb temperatures with sling psychrometer, wind direction and velocity, and state of weather.

7. Observations for atmospheric refraction by dip-of-horizon measurers at 8 a. m., noon, and 4 p. m. Atmospheric refraction was measured also by occasional sextant observations on the sun or Venus when these bodies were near the zenith.

8. Observations were made of the occurrence of thunder and lightning at sea.

Need of further weather observations over the oceans.—Some of the considerations leading to further extended observations over all the oceans on a scientific vessel may be described briefly as the general need for more information about the atmosphere over this relatively unknown two-thirds of the earth's surface, and the particular need for observations of known accuracy and for data from the little traveled ocean expanses that would be crossed by the *Carnegie*. The importance of oceanic centers of atmospheric high and low pressure in the seasonal weather conditions of the continents is becoming appreciated more and more as world weather is investigated. While some areas are well covered with reports, others are very sparsely sprinkled. From some parts of the South Pacific the Weather Bureau a few years ago was receiving but one vessel report per year per 3,000,000 square miles—an area like that of continental United States. And this report was of unknown accuracy, coming from a merchant vessel. Observations by the *Carnegie* on previous cruises and on the present and future ones, in this single area for example, will bulk large in the total scientific knowledge of that part of the earth's surface. Since there is no prospect for fixed observatories over vast stretches of ocean, our knowledge of ocean climatology must be built up by continuing to collect weather data here and there over the oceans wherever and as often as scientific vessels can be sent.

It is perfectly true that observations made with a moving observatory can do no more than note a sample of the climate of each spot passed over. And it is also obvious that unless such samples are recorded now, more next time and more another time, as a vessel passes that way, we shall never have enough of the samples on which to base a general idea of the annual course or ranges of the climatic elements. Each series of samples in intself does not have the value that a corresponding series of depth determinations enjoys, it is true. But that is the nature of what is being observed and does not indicate that this unexcelled opportunity for observing shall not be embraced to the utmost.

Need for ocean-wide observations in greater detail.—Simple observations of air temperature, humidity, pressure, wind, cloudiness, weather, and surface sea temperature, even when indefinitely multiplied by accurate recording apparatus, are very valuable in their way, but fail to show (1) The intensity of solar and sky radiation, (2) the heat budget and storage in the surface layer of the sea, (3) the heat exchange between sea and air, (4) the evaporation from the sea, and (5) winds at various heights.

Comparison of world weather with solar radiation is unsatisfactory without this information, or at least an index to the relative values for different parts of the world at different seasons. The heat exchange of the atmosphere over the oceans—more than two-thirds of the entire surface of the earth—is but little known. Knowledge of evaporation over the oceans can be stated only in the most general terms. We do no know the rate at which the atmosphere is being charged with water vapor vital to the life of the continents. The dynamics of atmospheric circulation over the oceans, and the general circulation of the atmosphere is very imperfectly known, because accurate observations are lacking for such large areas.

The new kinds of observations needed for all the oceans at all seasons are as follows:

(1) Temperatures of the surface layer of the ocean: Surface, 5 meters and 25 meters.

(2) Temperature and humidity lapse rates from sea to masthead.

(3) Wind directions and velocities at different heights, through balloon drifts and cloud motions.

[1] A running account of the successive trips by Capt. J. P. Ault is being published in Terrestrial Magnetism and Atmospheric Electricity, Washington. The trips from Washington to Callao are described in the September and December numbers, 1928, 33: 121–128; 192–194, and the March issue, 1929, 34: 26–31.

[2] Cf. J. P. Ault, The purpose and progress of ocean surveys. *Scientific Monthly*, February, 1928, p. 160–177, 14 ills. Also, in modified form, in *Jour. Washington Acad. of Sciences*, Mar. 4, 1928, 18 : 109–123, map.

[3] See "The steamship *Meteor* survey of the tropical and south Atlantic Ocean," 1 fig. MONTHLY WEATHER REVIEW, February, 1929, 57 : 60–63.

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(4) Solar and sky radiation.
(5) Evaporation of sea water. Sea salinities at surface and moderate depths.
(6) Cloud systems, rainfall amounts, dust counts, CO_2 in the air.

All these, happily, could be included in the *Carnegie* program.

The instrumentation includes recorders, so far as practicable. For sea temperatures a bulb-and-capillary type of sea-water thermograph with daily movement has been installed with the thermal element in the keel, about 2 meters below the surface.

Temperature and humidity lapse rates are being continuously recorded with a Hartmann and Braun electric resistance thermograph having three pairs of thermal elements (dry and wet), on the quarter-deck in the shelter, on the crosstrees, and at the top of the mainmast. This apparatus, installed in Hamburg, has given very satisfactory service. The lapse rates recorded are usually normal, while over cold currents the characteristic inversions of temperature occasionally appear. An overheating of the shelter on deck one calm day is recorded as an excessive lapse rate.

For a standard, a bulb and capillary ventilated Negretti & Zambra thermograph is provided in the shelter on the quarter-deck. The difference in the appearance of the mechanically written record of this instrument and of the electrically stamped dot record of the Hartmann & Braun is striking. The constant slight ups and downs of air temperature and the larger variations in wet-bulb temperature, to be noted when a psychrometer is held in the wind on a moving ship, is the cause of some of this broadening of the trace of the Negretti & Zambra instrument. In fact, sometimes for days the wet-bulb temperature will vary a few tenths to 1° C., in the course of 1 to 10 or more minutes while the air temperature remains essentially constant. This instrument is checked daily by an Assmann aspiration psychrometer.

In quiet weather, observations may be made from nearer the water from a small boat, with the Assmann instrument.

Pilot-balloon work was begun when the *Carnegie* left Balboa, thanks to the new theodolite supplied at Balboa by the United States Navy Department. This theodolite, on gimballs, keeps horizon and balloon together and independent of the motion of the instrument as a whole.[4]

"The good weather experienced," writes Capt. Ault,[5] gave splendid opportunity to observe the flights of pilot balloons * * * Practically daily flights were observed; on occasions the balloon could be followed for over one hour before it disappeared, the average being about 20 to 30 minutes. With winds of force 5 Beaufort scale, the balloon would disappear in 13 minutes. Two balloons tied together gave better results. The resulting determinations of the velocities and directions were from sea-level up to a height of from 2 to 6 miles." Six or nine inch red or uncolored balloons have been used, with a computed ascensional rate of 180 or 198 m/min., but, owing to rapid disappearance in brisk winds, red 9-inch balloons inflated to a 250 m/min. ascensional rate will probably be employed hereafter.

The balloons are followed with a sextant as well as with the theodolite. (See figs. 3, 4, and 5.) The sextant has been ingenuously hung on a spring from a bracket over a deck chair, in which the observer reclines at his ease. (Fig. 5.) This has been named the "Joshua chair" after that biblical character who commanded the sun to stand still. Under such favorable conditions the sextant proves to be a good balloon instrument, Captain Ault reports. A total of 44 pilot balloon runs had been made before reaching Callao, while the last radiogram gives 90. These observations constitute a notable addition to knowledge of the winds over the tropical Pacific.

Observations of cloud motions are being made with the balloon theodolite.

For the surface wind direction and velocity, reliance must be placed on estimates, as in the past, except for the indications of a hand anemometer (fig. 6, on box), which is being used particularly in connection with special series of observations of lapse rates and of evaporation.

For solar and sky radiation measurements a Moll solarimeter was supplied. This consists of two horizontally exposed blackened thermocouples, one of which connects with the metal base, covered with a small hemisphere of glass. A microammeter indicates the current generated by the heating effect of the radiation. Dr. Andrew Thomson, director of the Apia Observatory, Samoa, hopes that these observations will show whether a difference exists between stations on land and at sea. The effects of convection even on small islands, such as Samoa, may produce considerable variation in the transmitted radiation from that at sea. Thus far the solarimeter has been little used, chiefly because of the heavy demands of the other work upon the staff.

Evaporimeter and rain gage in turn occupy the same gimbals near the stern. (Figs. 6 and 3.) Continuous sums of evaporation are not being attempted, but observations are being obtained on favorable days. Twelve series were made before reaching Callao. The amount of evaporation is determined by the change in the salinity of the sea water used. The salinity is determined electrically.

Cloud systems are observed regularly at 7 a. m., 2 p. m., and sunset. The heights of cloud bases are being determied from time to time when pilot balloons enter clouds. Dust counts are being made with the Owens dust counter. Of CO_2 observations Prof. B. Helland-Hansen wrote:

> In connection with these ordinary hydrometeorological observations it would be most interesting if a general survey from different oceans can be made with regard to the tension of carbonic acid in the ocean and the atmosphere. As you know, the ocean acts as a buffer with regard to the variations of carbonic acid in the atmosphere, but far too few observations have been made on this point. I suppose the great expedition may furnish us with a classic material in this respect * * *.

Such are the numerous meteorological observations being made on the *Carnegie*. The scientific staff is most industrious, for this meteorological program is but a part of the whole gamut of observations magnetic, atmospheric-electric, biological, and physical oceanographic.

Conclusion.—The meteorological world is to be congratulated on the success already attained and the prospect of a further collection of such careful and comprehensive information from all the oceans; and the Carnegie Institution of Washington, Dr. John C. Merriam, director, and the Department of Terrestrial Magnetism of that institution, Dr. Louis A. Bauer, director, are to be highly commended for making this cruise possible. To J. A. Fleming, assistant director of the department, and to Capt. J. P. Ault, commander of the yacht *Carnegie* belong the chief credit for the program, preparations, and smooth accomplishment.

[4] Cf. F. W. Reichelderfer, Recent types of pilot-balloon theodolites for use aboard ship. Bull. Am. Met'l. Soc., 1928, 9:151-152.
[5] Loc. cit., 1929, p. 28.

[6] Described by L. Gorczynski: Some results obtained by testing solarimeters with pyrheliometric tubes. MONTHLY WEATHER REVIEW, 1927, 55: 488-490, 3 figs.

(To face p. 197)

FIGURE 4

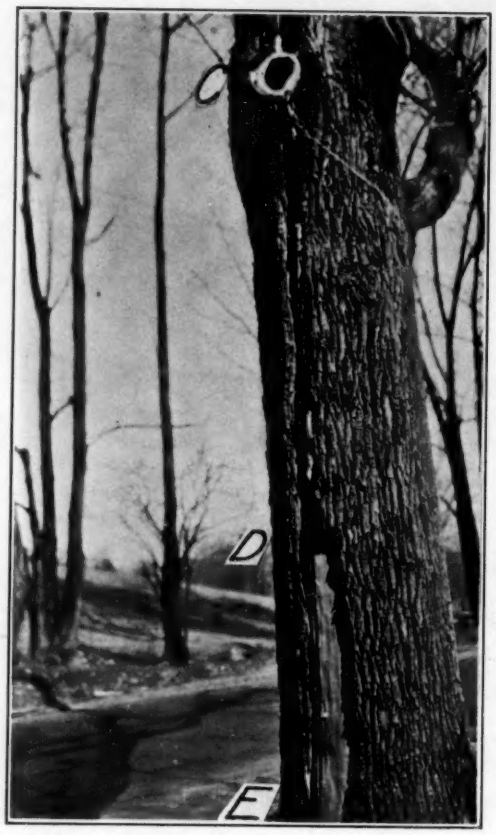

FIGURE 5

FIGURE 6

FIGURE 7

AN UNUSUAL LIGHTNING FLASH

By ALEXANDER MCADIE

One is almost tempted to say that lightning flashes are as a rule unusual because we note so many vagaries and departures from what we might expect. The discharge under consideration occurred April 26, 1929, about 11:55 a. m. on Canton Avenue, Milton, Mass., near the entrance to the grounds and residence of W. E. C. Eustis. The tree struck, a healthy ash, about 15 meters in height, stands on the east side of a paved avenue, 9 meters in width. There are other trees lining the avenue, which runs north and south, and there is a stone chimney east of the tree, the top being about 10 meters above the ground. One would naturally expect that the chimney rather than the tree would have been struck and damaged, for there is no lightning rod nor any metal roofing. Why the house (an entrance Lodge) was not struck and some damage done, we can not explain. The occupants state that they felt a heavy jar and heard a loud report and realized that something quite near had been struck; also that the thunder was practically instantaneous with the flash and jar.

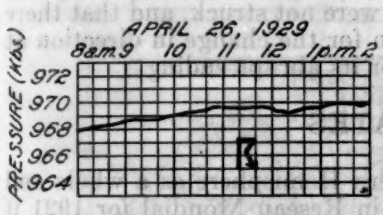

FIGURE 1.—Barograph trace

On the west side of the avenue there are poles carrying electric light, telephone, and telegraph wires. One such can be seen in Figure 1, and it will be noted that the crossbars carrying telegraph wires, six in number, are as high above the ground and in every way as much exposed to a lightning hazard as the tree would seem to be. In all there are 10 metallic conductors and if the line of electrical strain between cloud and earth moved, as we assume that it did, from southwest to northeast, it must have passed across these wires a second previous to the discharge. If on the other hand, the line of strain moved from east to west, the building, especially the chimney, being on higher ground, should have been struck. We find it hard to explain why this particular tree was hit, when other trees north and south of it, the poles and wires to the west, and the house to the east, were not injured in the slightest degree.

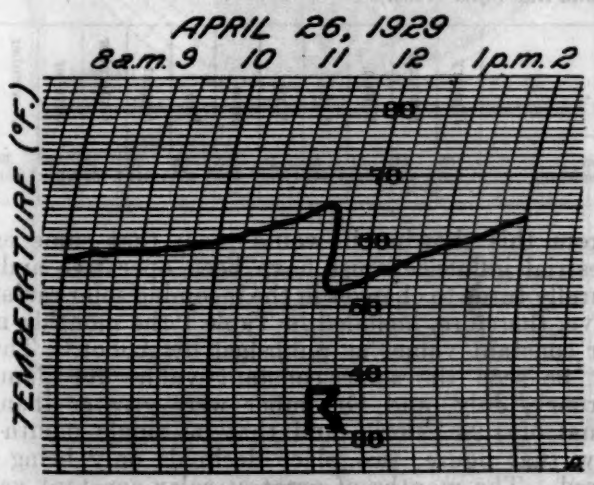

FIGURE 2.—Thermograph trace

The location is due north of Blue Hill, distant about 1 mile. The instruments at the observatory show that an hour previous to the storm, i. e., at 10:30 a. m., the surface wind was blowing from SW. by S. (230°) with a velocity of 12 meters per second (24 miles an hour) while the dark base of a large cumulus (but not as yet cumulonimbus) was 1,125 meters above the hill, moving from 225° with a velocity of 20 meters per second (33 miles an hour). The surface air temperature was 292° A. (66° F.) and the temperature at the base of the cloud 281° A. (49° F.). The surface relative humidity was noticeably low, being only 50 per cent, and the absolute humidity 8 grams per cubic meter of space. The vapor pressure at the ground at saturation would be 22 millibars (or kilodynes per square centimeter) and the vapor density 16 grams. It is thus plain that there existed near the ground a stratum of air that was relatively dry and so constituted a good insulating layer between cloud and earth. The aerostatic pressure was rising steadily but slowly from 968 millibars or kilodynes at 8 a. m. to 970 at the time of the flash. The barograph records do not show any characteristic thunderstorm notch, and here again the storm was unusual in that while there was a quick drop in temperature there were no noticeable wind shift or pressure discontinuities. In fact we regarded it at the time as a rather mild and unimportant thunder shower, although there had been at least one vivid straight line vertical flash in the west.

The bolt appears to have entered the tree not at the extreme tips of the upper small branches, but about 1 meter below, and we trace it first at the point marked "A" (fig. 4) on a branch about 10 centimeters in diameter. There is a straight groove on the top side of the branch, the bark being gouged out, varying from 1 to 4 centimeters in width. The groove is about 1 centimeter deep. The path follows the branch to the trunk and then goes practically in a straight line to the ground, down the south side of the tree.

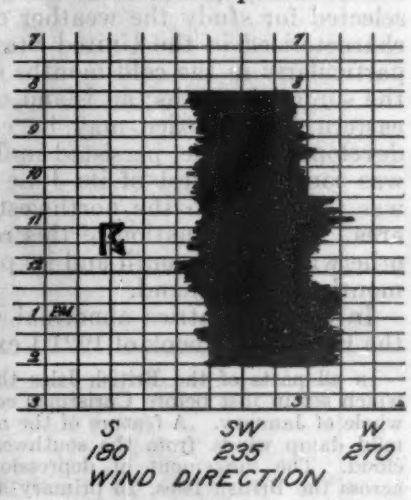

FIGURE 3.—Wind direction

At the point B (see fig. 4) a thicker branch joins the tree and there is just the slightest bend in the path of discharge but no tearing off of the bark or other damage than the path itself. At the point C, a large branch had at some earlier date been cut off (see figs. 4 and 5) leaving a nearly circular exposed part of the wood, 17 centimeters in diameter. Just to the right, i. e., to the east about 30 centimeters distant and less than 10 centimeters above the first, is a second circular opening, where another slightly larger branch had been cut off. Before the flash, both trimmings were dark and weather stained. The larger one remains so and was in no way affected. The smaller one had its outer ring of protecting bark torn off and the cambium exposed. The discoloration is complete and the flash evidently went around the spot in both directions. This is an interesting point, as showing that in this case at least lightning took the path of least ohmic resistance, which generally is not characteristic of discharges of extremely

high voltage. We may estimate the voltage of this flash as of the order of 15,000,000 volts. The current intensity may have been 1,000 amperes; but these are only rough approximations. The cambium circle C (fig. 5) is 9 feet above the ground and the circumference of the tree at this point 150 centimeters. The circumference at the ground 250 centimeters. From C, the path is a shallow groove, with a deep V-shaped groove in the center, running down the tree to a point D (see figs. 5 and 6) where an explosive effect is seen, the water content of the cambium being evidently converted into steam at high pressure by the intense heat with the result that the bark was blown out and away. On both sides of the bare area, the bark is loosened to such an extent that a finger can be inserted between the bark and the cambium.

In Figure 6 a deeply cut inner groove can be seen, almost straight. This can be traced down to the ground (humus). In Figure 7, E, F, and G, the path can be distinctly seen as it plunges into the ground. Running directly west, the lightning made a clean cut furrow turning up the sod for a distance of 130 centimeters. In general the depth is 1 centimeter and width in places 13 centimeters. Reaching the limit of the sod, where a gutter of the road begins—that is, a mixture of broken stone and asphaltum—the furrow disappears, and we assume that the energy of the discharge was at last completely dissipated by this grounding.

The disruptive effects seem to be more marked at the bottom of the tree than at the top. Indeed, small branches and even twigs near the top and for some distance down, although quite near the path, that is, within 5 centimeters, were not injured in the least. This seems remarkable and we must assume a strong directive force in a vertical plane, and no splitting or side flashing. With most lightning discharges the disposition to split into branch discharges is marked. In near lightning this is also the case and in the 5,000,000-volt flash (near lightning) now used by F. W. Peek, jr., of the General Electric Co. in experimental work, as well as in the 3,000,000-flash shown in the MONTHLY WEATHER REVIEW, June, 1928, page 218, side flashes both up and down are to be seen clearly.

This flash then was unusual in that there is no twisting of the path, in that near-by and seemingly more exposed poles, trees, and buildings were not struck, and that there is no apparent explanation for the change in direction at the ground surface, nor for its abrupt ending.

WEATHER ABNORMALITIES IN UNITED STATES [1]

ALFRED J. HENRY

(SECOND NOTE)

Continuing previous studies on this subject I have selected for study the weather of 1921. This year was characterized in the United States by unusual warmth, particularly in the cold months of the year as well as in the summer months; an island of cool weather of which eastern New Mexico may be considered as the center developed in June, persisted in July although the center was somewhat west of its June position and in August was found far to the northwest and much enlarged in area. The explanation of this restricted cool area in an otherwise warm month and its persistence through three months is not at hand.

In other countries abnormal weather prevailed; from the British Yearbook of 1921 I excerpt the following:

In all parts of the British Isles the abnormally mild weather which set in just before Christmas continued nearly through the whole of January. A feature of the month was the persistence of mild damp winds from the southwest or west, with much low cloud. The movement of depressions was generally eastward across the British Isles, 16 primary and 2 secondaries have been charted.

February: The pressure distribution over west and northwest Europe during the month was largely dominated by a series of important anticyclones. Depressions followed paths well to the northward or southward of the British Isles. A very dry month in England and Wales.

March: The conditions over northwest Europe during March were of a westerly to southwesterly type, with frequent depressions in the neighborhood of the arctic circle and relatively high pressure between the Azores and Europe. As in the two preceding months there was a marked absence of severe wintry weather over western Europe generally and ever in Sweden there was little frost after the 9th. Brief incursions of polar air were accompanied by snow in the northern districts of the British Isles at times in the first week, and in western districts on the night of the 28th but milder weather followed in each case. Ten depressions were charted moving almost due east about latitude 65.

June was very dry, July fine and warm, August unsettled, September mostly fine and warm, October very warm, sunny and dry, November cold, dry, and foggy, and December unsettled, mild, and windy.

[1] cf. Henry A. J. Weather abnormalities in United States this REVIEW, Vol. 56.

Considering the Northern Hemisphere as a whole and using the data published in Reseau Mondial for 1921 it would appear that for the most part the year must be classed as a warm one.

In that publication the records of 269 stations having normal temperatures are given with the deviation from normal for each station. Combining these in a table by months it is found as shown in the table below that only the months September to November were relatively cool. The table follows:

TABLE 1.—*Per cent of stations in Northern Hemisphere having positive departures in 1921. Mean monthly solar constant values in second line (after Abbot)*

	January	February	March	April	May	June	July	August	September	October	November	December
Per cent	68	54	61	54	58	53	58	50	43	49	39	58
Solar constant	1.955	1.956	1.949	1.944	1.943	1.939	1.956	1.944	1.909	1.962	1.951	1.953

From this showing it would seem that some extra-terrestrial influence must have been operative and one naturally turns to changes in the incoming solar radiation. I have, therefore, included in Table 1 the monthly mean solar constant values as published by Abbot.[2] Thus it may be seen the solar constant values for January, February, July, and December were greater than the normal of 1.94 calorie, and that no single month was below that figure, two place decimals only being considered. The months of greatest solar constant values, however—September and October—were not associated with pronounced terrestrial temperature departures.

The sun-spot numbers for 1921 were not large; the minimum of 1923 was approaching. While the increase in solar radiation does not closely tie up with increased terrestrial temperatures it can not be dismissed from consideration. It might be argued that the effect of an increase or decrease in solar radiation should be felt more

[2] Abbot, C. G. Smithsonian Misc. Coll. Vol. 80, No. 2, p. 6.

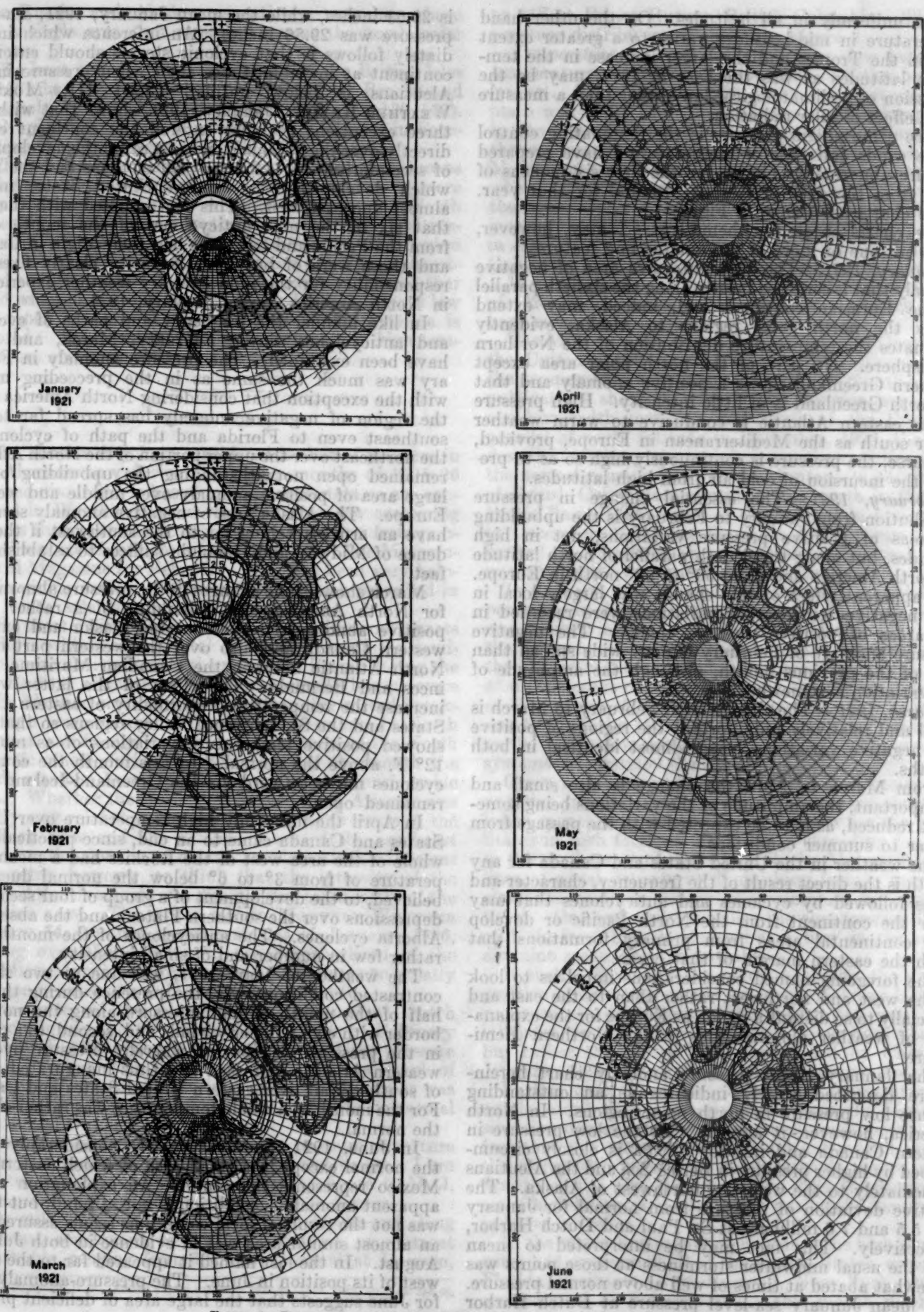

FIGURE 1.—Pressure-abnormality charts for Northern Hemisphere, January–June, 1921

or less uniformly in all latitudes. On the other hand temperature in mid-latitudes varies to a greater extent than in the Tropics and the larger increase in the temperate latitudes as was the case in 1921, may be the expression of a climatological law rather than a measure of the effect of solar radiation.

Since atmospheric pressure is the dominating control of the winds and thus of temperature I have prepared pressure abnormality charts for the first six months of 1921, from the data of Reseau Mondial for that year. These charts are shown in Figure 1.

The charts speak for themselves. I may, however, point out one or more of the outstanding features.

January, 1921.—The very extensive area of negative anomaly that is centered mostly along the sixtieth parallel of the Eurasian continent and, indeed, may extend across the north polar regions to Alaska, evidently dominates the temperature distribution of the Northern Hemisphere. No part of the north polar area except northern Greenland shows a positive anomaly and that of North Greenland is of little intensity. High pressure in the eastern Atlantic is conducive to warm weather as far south as the Mediterranean in Europe, provided, of course, the pressure is continuously high so as to prevent the incursion of cold air from high latitudes.

February, 1921.—The essential change in pressure distribution from January to February is the upbuilding of areas of positive pressure variations, not in high latitudes, but along the fiftieth parallel of north latitude in North America and from 50° to 60° north in Europe. The apparent effect of this change was largely local in that negative temperature variations were recorded in the areas of positive pressure change. The negative pressure anomaly of February is more wide spread than that of the previous month, although the amplitude of the variation is somewhat less.

March, 1921.—The change from February to March is small and relatively unimportant the regions of positive and negative variations being almost identical in both months.

From March to April the change is also small and unimportant, the amplitude of the variations being somewhat reduced, as is to be expected with the passage from winter to summer conditions.

The weather in the United States and Canada for any month is the direct result of the frequency, character and paths followed by cyclones and anticyclones that may enter the continent from the North Pacific or develop over continental areas from primary formations that reach the eastern margin of that ocean.

The foregoing named considerations impel us to look to the west and northwest rather than to the east and especially to so distant a region as Europe for the explanation of weather abnormalities in the Northern Hemisphere.

The January, 1921, pressure anomaly chart hereinbefore described clearly indicates as an outstanding feature low pressure in north polar regions. In North America, however, it appears that the low pressure in western Canada and interior Alaska is closely circumscribed by higher pressure in Bering Sea and the Aleutians immediately to the west and northwest of Alaska. The positive deviation of pressure from normal for January was 5.5 and 7.6 millibars at St. Paul and Dutch Harbor, respectively. This fact may be interpreted to mean that the usual midwinter storminess at those points was somewhat abated at times of well above normal pressure. The mean January sea-level pressure at Dutch Harbor is 29.63 inches, while the mean January, 1921, sea-level pressure was 29.86 inches. An inference which immediately follows is that cyclonic storms should enter the continent at lower latitudes than when pressure in the Aleutians is below normal. Chart III, MONTHLY WEATHER REVIEW, January, 1921, shows that with but three exceptions cyclones entered the continent either directly over the Washington coast or by the development of secondaries over Alberta. All of these and the three which developed over western United States moved almost due east/west. This fact coupled with the fact that six of the nine anticyclones of the month came from the Pacific and but three had their origin in Canada and those were of but little intensity clearly fixes the responsibility for the mild January weather experienced in North America during January, 1921.

In like manner the frequency and paths of cyclones and anticyclones during February, March, and April have been examined. The pressure anomaly in February was much the same as in the preceeding month with the exception that considering North America only, the region of negative anomaly has spread far to the southeast even to Florida and the path of cyclones to the northeast over the upper portion of the North Atlantic remained open notwithstanding the upbuilding of the large area of positive anomaly over middle and western Europe. The Alaska area of negative anomaly seems to have an arm stretching far to the southwest if the evidence of Midway and Honolulu suffices to establish that fact.

March shows some changes in the pressure abnormality for North America, the upbuilding of a rather small positive abnormality over coastal Alaska and extreme western Canada and also over the western part of the North Atlantic between the Canadian Maritime Provinces and Bermuda. The effect of the latter was to increase the temperature abnormality of eastern United States and the St. Lawrence Valley regions so that each showed positive temperature variations of as much as 12° F. above the normal. In this month the course of cyclones northeastward via the Greenland-Iceland route remained open.

In April the uniformly high temperature over United States and Canada came to an end, since practically the whole of the area west of the Rockies had a mean temperature of from 3° to 6° below the normal due, it is believed, to the development of a group of four secondary depressions over the southern Plateau and the absence of Alberta cyclones. The anticyclones of the month were rather few in number and of small intensity.

The weather of May, 1921, was due to two sharply contrasted conditions, viz, the presence during the first half of the month of high pressure along the northern border with cool northerly winds and, second, to a change in the pressure distribution whereby pressure over the weatern Atlantic increased and thus inaugurated a flow of southerly air over eastern United States and Canada. For the month as a whole temperature was rather close to the normal.

In June, 1921, temperature was considerably above the normal except in a small area of which eastern New Mexico represents the center. An explanation of this apparent anomalous condition is not at hand, but that it was not the result of local conditions seems assured since an almost similar area was in evidence in both July and August. In the last named it appeared far to the northwest of its position in June. The pressure-anomaly chart for June suggests that the large area of deficient pressure

over Russia and Alaska, respectively, may have been but a single area that stretched across the north polar regions.

The heat and drought experienced in the British Isles in 1921 has been studied in great detail by Brooks and Glasspole (Quart. Jour. Roy. Met. Soc. 48: 139–168). Sir Napier Shaw has also written on the subject in Forecasting Weather, pages 119, 173, 375, 556.

The world-wide bearing of pressure anomalies in Europe and Asia on the weather of the United States, or more properly speaking on the weather of temperate North America, as I see it, lies in the fact that great positive-pressure anomalies over the Greenland-Iceland region will block the free advance of cyclones passing northeastward over the United States and Canada, and on the other hand when pressure in the high latitudes of Europe is low the rapid advance of cyclones over North America is favored. The rapid movement is favorable to high temperature and little precipitation.

(THIRD NOTE)

The abnormality here considered is that of pressure in the Aleutian LOW during the winter months of 1925–26 and the discussion is based on only such data as are contained in Weather Bureau records plus a few scattering reports that have been compiled by the author from published reports of foreign weather services. The Meteorological Magazine for February, 1926, has been very helpful in giving a view of the conditions which prevailed in the North Atlantic and the British Isles.

The outstanding features of the weather in various parts of the world were the total disappearance of the semi-permanent anticyclone of the northeast Pacific during the last 10 days of the month, the abnormally low pressure in the Aleutian semipermanent cyclone, the record-breaking high temperatures in Alaska and elsewhere in North America and finally the unusual storminess of the North Atlantic where during the latter part of the month the winds attained hurricane force over a very considerable area. Whether the storminess in the North Atlantic was in any way related to the low level of the pressure in the Aleutian LOW and the disappearance of the northeast Pacific anticyclone is, of course, problematical. It seems reasonable, however, to think that the intensity of the North Atlantic storms was directly due to intensity of the Aleutian LOW. The writer said in MONTHLY WEATHER REVIEW **54**: 70 that cyclonic storms of January, 1926, passing over the Atlantic in the neighborhood of the Canadian Maritime Provinces had a tendency to greatly increase in intensity as in the previous month.

The center of the Aleutian LOW remained at Dutch Harbor during the two succeeding months of February and March, 1926, though the mean level of the pressure rose somewhat, the sharp rise from the low level of January did not come until in April and May and it was not until June that pressure returned almost to its normal level at the Dutch Harbor station.

Some idea of the magnitude of the pressure departure in the Aleutians may be had from Figure 1 below. I am indebted for this and the next following figure to H. J. Thompson [1] who originally prepared both figures.

The mild temperatures experienced in Alaska and along the coast southward to British Columbia, were most remarkable, ranging from 30° above normal at Dawson, to 11° at Prince Rupert, British Columbia. The temperature distribution is shown in Figure 2.

Temperature.—There are, of course, few long-period temperature records in Alaska, that of Sitka being the longest. The January, 1926, mean temperature at that place was 43.2° F.—a mean temperature corresponding to the January normal in the latitude of Atlanta, Ga., thence westward across northern Alabama, northern Mississippi and Texas and continuing thence to the point where it emerges upon the Pacific at latitude 42° north, on the boundary between California and Oregon. Hence it is seen that the temperature experienced at Sitka, Alaska, in January, 1926, was normal to the latitude of northern California, more than 1,000 statute miles to the southward.

It would seem as if the mark made by the mild winter of 1925–26 in Alaska would stand for a century or perhaps more.

The MONTHLY WEATHER REVIEWS of both Canada and the United States portray graphically the variation of the temperature from normal month by month. These publications show that for North America west of the one hundredth meridian and north of the thirty-fifth parallel of north latitude in December, 1925, the above described territory was unduly warm the variations above the normal ranging from 10° in Montana to 14° in parts of British Columbia and still farther north in the Mackenzie Basin. The cause of the increase in temperature in December, 1925, was the same, low pressure and its control of the winds, as brought about the peak of the warming in the next succeeding month.

In January, 1926, the peak of the relatively high temperature, as shown by the departures from the normal, was reached in the Yukon Valley at Dawson, 30° above the normal, diminishing thence to the border between the United States and Canada, where it amounted to but 4° on the coast rising to 12° along the border as far east as Winnipeg. A part of this warming must have been due to the foehn effect as the westerly winds descended to the lower elevations to the eastward of the mountain systems that parallel the coast.

Great variations in the temperature both positive and negative frequently appear on the departure chart published monthly in the WEATHER REVIEW for the United States in such form as to suggest a spreading fan-shape to the southeastward east of the Rocky Mountains of the lines of equal departures diminishing from a maximum along the northern border to a minimum in lower latitudes. One can easily visualize the equatorward flow of cold air from high latitudes but a flow in the reverse direction seems quite improbable.

If such a flow did take place, naturally the greatest positive abnormality would be found in lower latitudes, progressively diminishing with penetration into higher latitudes. Such a distribution has never been observed but rather the contrary, as exemplified by Chart III, January, 1926 MONTHLY WEATHER REVIEW, vol. 54.

In this case the cause of the high temperature can not be ascribed to southerly winds since the barometric situation demanded wind of northerly component. The fact that this unusual warming did not extend south of the thirty-fifth parallel of north latitude seems to confirm the belief that the down-slope drift of over-warmed air of high latitudes is effective in raising the temperature in lower latitudes.

In the succeeding month of February the high temperatures had overspread all of the United States, except the Florida Peninsula, New England, New York, and the greater part of Pennsylvania. This month marks the

[1] Cf. Thompson, H. J. Alaska's mild winter of 1925–26. Mo. Wea. Rev. 54: 256–60.

greatest southeastward thrust of the high temperatures of the far northwest. In March, while northwestern United States had temperature above the normal the greater part of the country had subnormal temperatures amounting to as much as 6° in the lower Ohio Valley and the northern parts of Alabama, Mississippi, and Georgia. In this month subnormal temperatures prevailed also in the Hudson Bay region, thence southwestward to Winnipeg and south practically to the Gulf of Mexico. In April immediately following while temperatures remained above normal in Alaska and thence south to the Mexican border, the eastward extension of the warm weather did not extend more than about 200 miles from the coast on the south but at least to Winnipeg on the north. (See Chart III, April, 1926, REVIEW.)

Variations in elements other than temperature—Pressure.—The swing of pressure in the Aleutian LOW was one of long period, in the sense that it was greater than a week or 10 days. Pressure began to fall in November, 1925, and did not return to normal until June, 1926, thus making a complete oscillation in about eight months. There was noticed in November, 1925, an increase in the intensity of the general circulation as manifest in the storminess over the North Pacific Ocean. Eighteen cyclonic storms were plotted as passing over continental United States during the month, several of which were of considerable intensity.

In December, 1925, the continental extension of the northeast Pacific anticyclone was centered over the Great Basin with a monthly mean pressure of 30.32 inches at Boise, Idaho. Coincidently with the presence of this anticyclone the oceanic anticyclone, which is usually found off the California coast, was greatly weakened and as a result cyclones moved east-northeast across the Pacific in paths somewhat south of the Dutch Harbor route. Evidently, since the number of cyclones and anticyclones that entered North America in December, 1925, was less than usual the shifting of the path of cyclones to the south, as above recited has no important bearing on the storminess of the United States.

Passing now to a consideration of the pressure distribution of January, 1926—the month during which the peak of the fall was reached—I wish to call attention to an article by Thomas R. Reed of the San Francisco Weather Bureau Office.[1]

Mr. Reed points out in his article that there was a change in the type of pressure distribution over the Pacific Ocean as shown in his two figures, reproduced as Figures 3 and 4 below. The essential feature of the change referred to is that pressure in the second period is lower than in the first and the anticyclone off the California coast shown in the first period has entirely disappeared in the second period. During the period January 1 to 24 pressure in the Great Basin anticyclone was high and cyclones were not able to enter the continent along the coast between British Columbia and Mexico. On or about the 24th pressure over the Great Basin began to fall as cyclones penetrated the continent north of the border between Canada and the United States; it was not, however, until January 31 that a cyclone was able to pass inland in the vicinity of San Francisco. Other cyclones followed and much needed rain fell in California and adjoining States. So far as surface observations are concerned there is no clue to the cause of the continued fall in pressure in the Aleutians which reached the low point of 28.4 inches on the average for the 10 days, January 24–February 3, 1926, and brought the level of pressure in the Great Basin anticyclone from its high value of 30.5 inches for the first half of the month to less than 30 inches in early February.

Pressure in the Great Basin anticyclone, as at Boise, Idaho, maintained a high level for the first half of January, not falling below 30 inches until the 17th; it then rose immediately well above 30 inches and did not again

[1] Reed, Thomas R. Average pressure for oceanic areas computed from daily synoptic charts, This Rev. 54: 1–2.

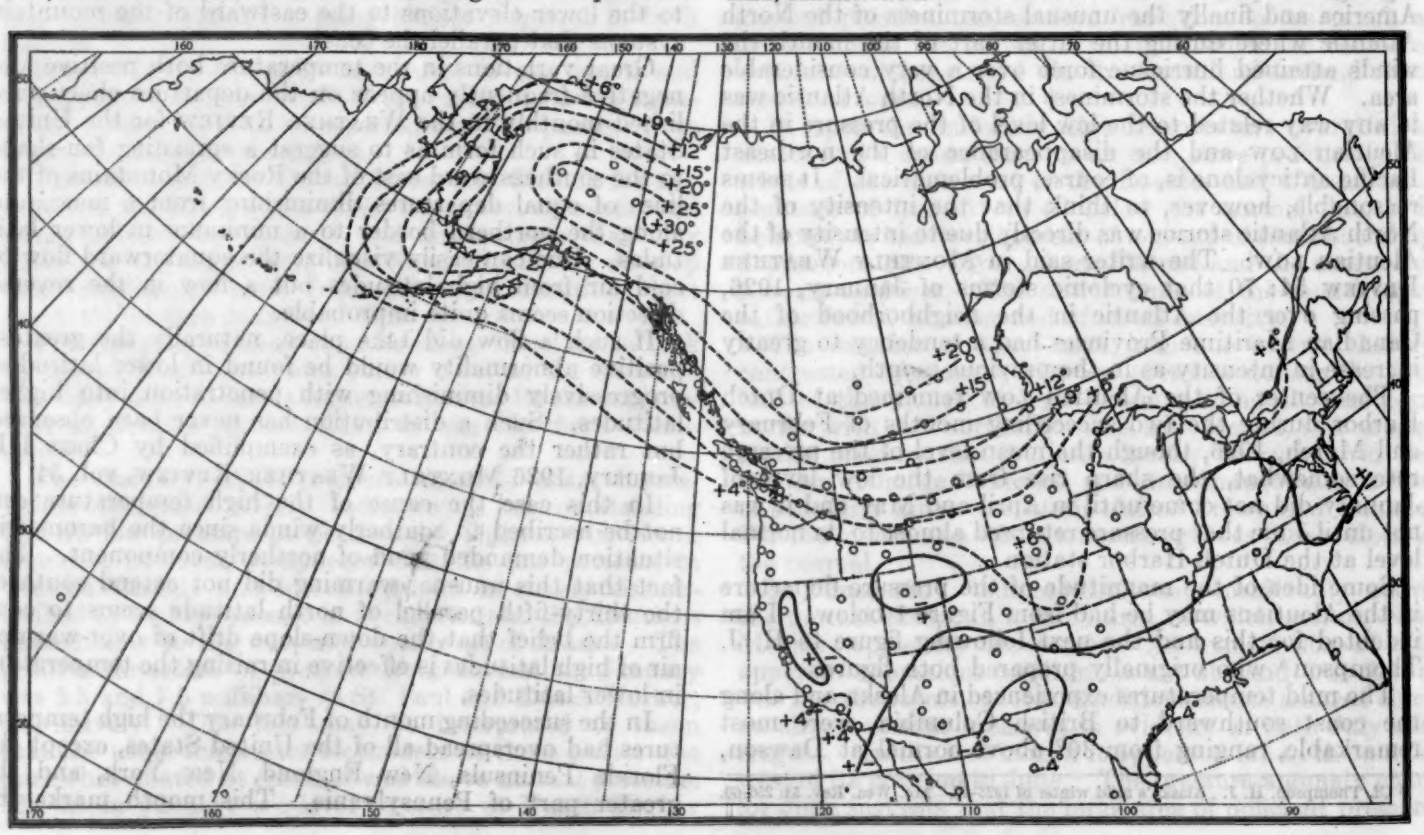

FIGURE 1.—Departures of temperature from the normal in Alaska, Canada, and part of the United States, January, 1926

descend to 30 inches until the 29th; it then rose to 30.09 inches and fell to 29.78 inches on the 31st of the month.

Alaska pressure in previous Januaries.—This discussion would be incomplete without reference to previous months of the same name having pronounced low pressure.

January, 1919, experienced the greatest dip of pressure below normal in Alaska previous to January, 1926, of which records are available. In that month the area of negative anomaly extended westward over the Aleutians and to the southeast across Canada and the United States to the Atlantic in the neighborhood of the Canadian Maritime Provinces, thence northeast to southern Greenland. The maximum negative abnormality in North America was 14.8 millibars at Tanana, Alaska. In Europe a rather large area of large negative anomaly stretched from the British Isles southeastward to the Mediterranean and indeed in less intense form to the Red Sea. On the opposite of the globe large areas of positive anomaly were present with the maximum abnormality of 16.5 millibars in high latitudes in Russia.

In the United States the weather was warm and dry, the warm weather, however, did not entend to the southern border of the United States, except in southern California and the lines of equal abnormality of temperature also show the southeastward spread as in January, 1926.

The pressure distribution in January, 1919, suggests the mass movement of cyclones across North America along the border between Canada and the United States, thence across the Atlantic in rather higher latitude than usual to northern Europe and thence a spreading more or less to the southeast. I have, however, no confirmatory evidence on the last point.

January, 1915.—This month, while similar in many respects to that of 1919, is different in others. The temperature in the United States in January, 1915, was quite unlike that of 1919, the distribution being a mixed one—warm in some portions and cold in others, perhaps due to the distribution and movement of cyclones and anticyclones—there being a greater number of anticyclones descending from Canada and a rather pronounced movement of cyclones across the United States in low latitudes than in January, 1919. Pressure over the Atlantic was higher than in that year and this may have been a factor in the distribution of temperature and rainfall.

January, 1914.—This month was unique among those considered in the fact that pressure was below the normal apparently over the greater part of the Northern Hemisphere especially in the higher latitudes. The negative anomaly evidently extended across the north polar regions and was most intense (had the greatest amplitude) at the Russian station Oust Tsylma and east of the Urals at Eneiseisk, northwest Siberia, the depression of the barometer at the two places being 0.58 and 0.43 inch, respectively. In North America a depression of 0.36 inch was noted at Prince Rupert, British Columbia, and 0.31 inch at St. Johns, Newfoundland.

The course of the cyclones that entered the United States from the Pacific was almost due east along the northern circuit, there being but two storms—both secondaries—that passed northeastward from the Gulf region. Anticyclones were about as numerous as usual and displayed no striking features, except that those occurring during the second half of the month lacked in intensity, thus in a measure accounting for the exceptionally warm weather in every part of the country save New England and the extreme southern tip of Florida.

January, 1921.—This month has been discussed in the second note on weather abnormalities; in this paper we shall content ourselves with the statement that it was a very warm midwinter month and was followed by two months each having temperature much above the normal. Pressure in Alaska was below the normal but not excep-

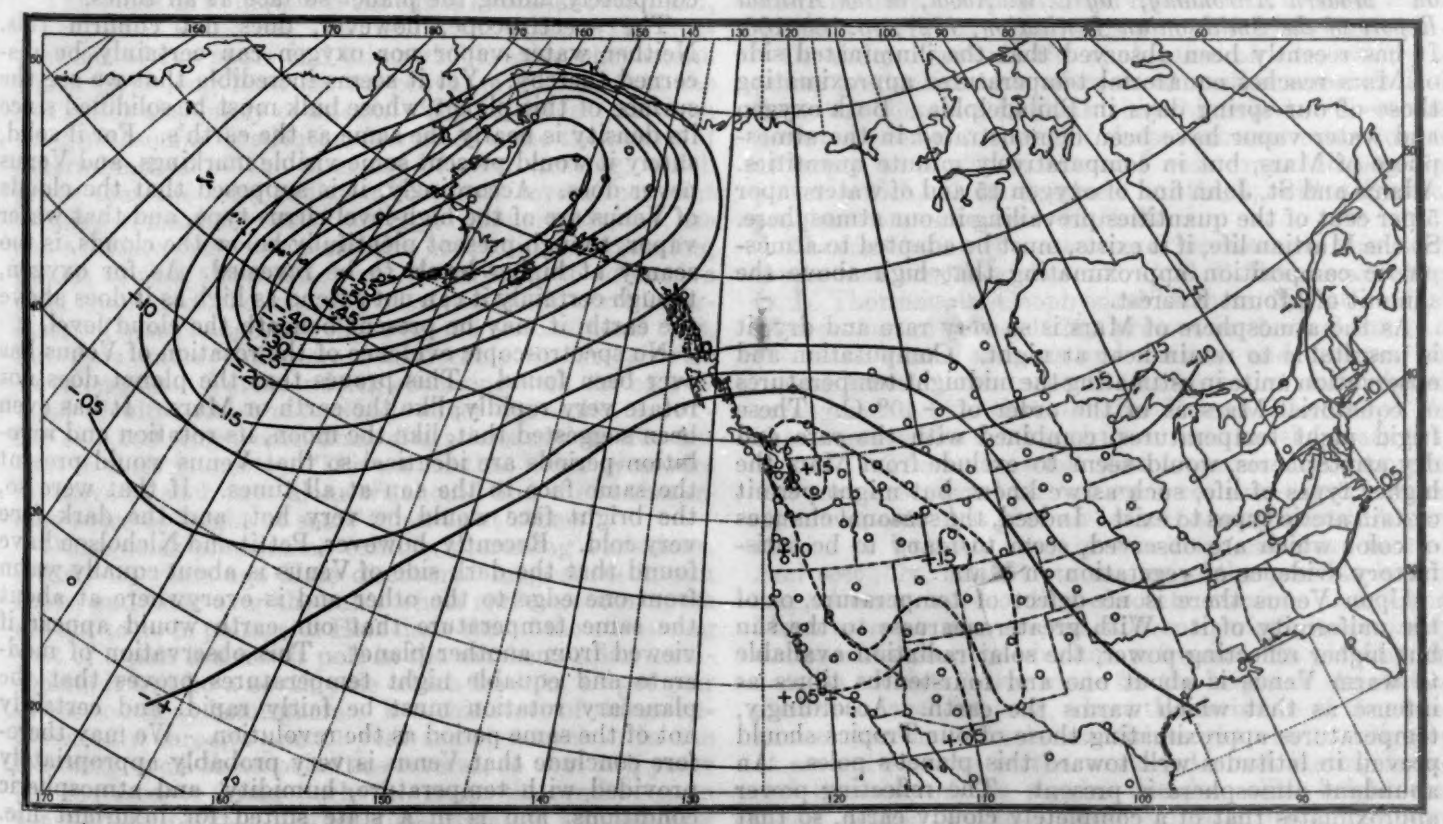

FIGURE 2.—Departures of sea-level pressure from the normal over the northeast Pacific and adjoining land areas for January, 1926

tionally so. This concludes the series of five Januaries with negative pressure anomalies in Alaska.

It seems reasonable to conclude therefrom that low pressure in Alaska and the Aleutians is concomitant with mild and rather dry weather in the United States, except that generous rains are probable in the Southeastern States.

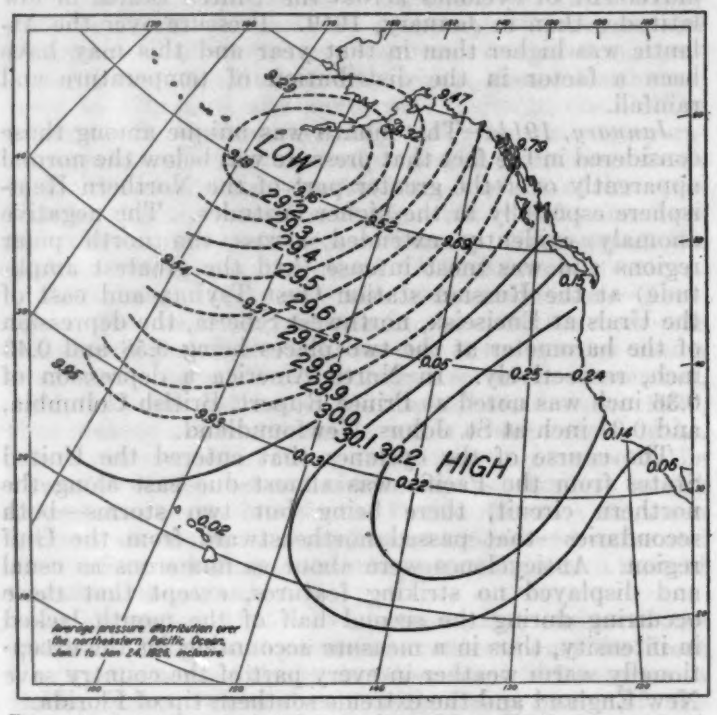

FIGURE 3.—Average pressure in inches over the northeastern Pacific January 1 to 24, 1926

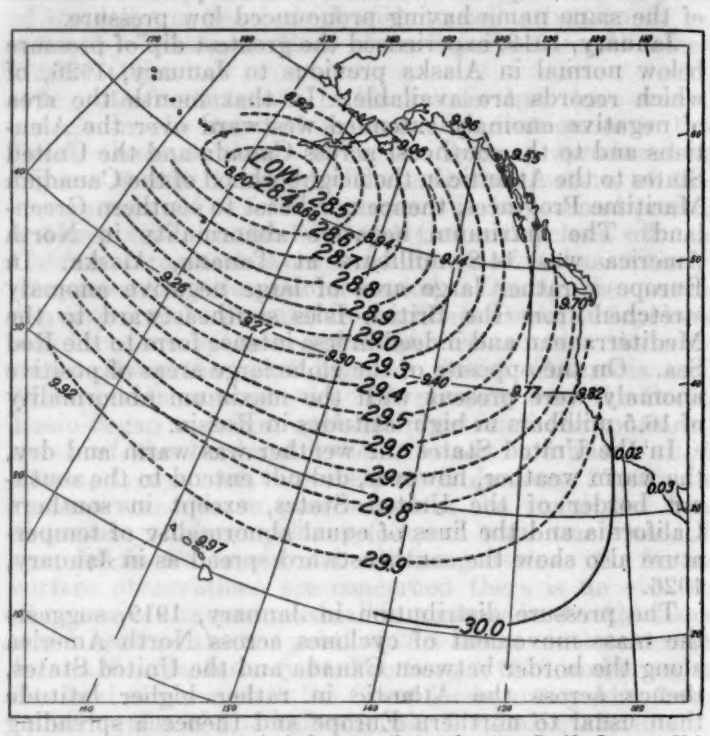

FIGURE 4.—Average pressure in inches over the northeastern Pacific January 25 to February 5, 1926

NOTES, ABSTRACTS, AND REVIEWS

Some human aspects of astronomy (excerpts from a paper on "Modern Astronomy," by C. G. Abbot, in the Annual Report of the Smithsonian Institution, 1927, pp. 163–166. It has recently been observed that the illuminated side of Mars reaches equatorial temperatures approximating those of our spring days in Philadelphia. Both oxygen and water vapor have been demonstrated in the atmosphere of Mars, but in comparatively minute quantities. Adams and St. John find of oxygen 15 and of water vapor 5 per cent of the quantities prevailing in our atmosphere. So the Martian life, if it exists, must be adapted to atmospheric composition approximating that high above the summit of Mount Everest.

As the atmosphere of Mars is so very rare and dry, it is unsuitable to retain heat at night. Computation and observation unite in estimating the midnight temperatures of equatorial Mars as of the order of −40° C. These frigid night temperatures, combined with the rare and dry atmospheres, would seem to exclude from Mars the higher types of life, such as we know, but might permit certain arctic types to exist. Indeed, the seasonal changes of color which are observed, seem to many to be satisfactory evidence of vegetation on Mars.

Upon Venus there is no defect of temperature, or of the uniformity of it. With greater nearness to the sun but higher reflecting power, the solar radiation available to warm Venus is about one and four-tenths times as intense as that which warms the earth. Accordingly, temperatures approximating those of our Tropics should prevail in latitudes well toward this planet's poles. An abundant atmosphere is present. The reflecting power approximates that of a completely cloudy earth, so that it would be reasonable to conceive of clouds of water, completely hiding the planet surface at all times.

The spectroscope, however, does not confirm this. Neither water vapor nor oxygen can certainly be discerned thereby. Yet it seems incredible that we see the surface of this planet, whose bulk must be solidified since its density is nearly the same as the earth's. For if solid, surely it would present some visible markings, and Venus never does. Accordingly, it is supposed that the clouds of Venus are of the high-level cirrus type, and that water vapor, though present plentifully below the clouds, is too scanty at higher levels to be revealed. As for oxygen, though certainly it can not extend as high as it does above the earth, it may be present beneath the cloud level.

No spectroscopic evidence of the rotation of Venus has ever been found. This proves that the planet does not rotate very rapidly, like the earth or Mars. It has even been suggested that, like the moon, its rotation and revolution periods are identical so that Venus would present the same face to the sun at all times. If that were so, the bright face would be very hot, and the dark face very cold. Recently, however, Pettit and Nicholson have found that the dark side of Venus is about equally warm from one edge to the other and is everywhere at about the same temperature that our earth would appear if viewed from another planet. This observation of moderate and equable night temperatures proves that the planetary rotation must be fairly rapid, and certainly not of the same period as the revolution. We may therefore conclude that Venus is very probably appropriately provided with temperature, humidity, and atmospheric conditions, and is in a state suited for luxuriant life.

Being wholly cloudy, however, it is doubtful if we can ever demonstrate it.

The earth, therefore, still remains the only known abode of life, and her life depends absolutely on the sun's radiation. Recent studies have shown that this dependence rests on very narrow margins of safety. For instance, the oxygen of the upper atmosphere is induced to combine into the form of ozone by the influence of extreme ultra-violet solar rays, and yet the ozone formed is continually being reconverted into oxygen by the influence of still other extreme ultra-violet solar rays. Thus occurs a balance of these effects such that the upper atmosphere contains so minute a quantity of ozone as would make, if brought to earth, a gaseous layer only as thick as a cardboard. Yet this minute and almost fortuitous atmospheric constituent cuts off entirely the spectrum of the sun and stars beyond wave length 2,900 Angstroms. The solar rays thus cut off, if they reached the earth, would destroy human sight and tissues by their powerful chemical activity. Of course, we could shield ourselves from these effects, but our ancestors who lived before the invention of spectacles would have lost their sight, or never attained it. Yet if the atmospheric ozone absorption reached only a little further, to 3,200 Angstroms, human and animal young would languish with the enfeebling disease of rickets, for the extreme ultra-violet rays are indispensable to proper mammalian growth.

As ozone absorbs to some extent even as far as 3,200 Angstroms, a catastrophe might ensue if circumstances led to a small increase of the ozone content of our atmosphere. For this would eliminate indispensable rays of wave lengths 2,900 to 3,200 Angstroms. Such a catastrophe would attend such an alteration in the distribution of the extreme ultra-violet solar spectrum as would change materially the existing balance of influences tending to produce and destroy ozone.

This leads us to inquire if the sun is a constant star, and, if not, what is the character of its variation. The fluctuations of sun spots and other visible solar phenomena which have long been known prove, of course, that the sun is not absolutely constant. Within the last 22 years the Smithsonian Institution has made some thousands of determinations of the intensity of solar heating, which prove that the solar radiation increases several per cent at times of maximum solar activity. Apparently, too, the sun's surface presents appreciable inequalities of radiating power, so that the rotation of the sun leads to successive brief changes of the intensity received at the earth's surface. These changes are slight for red and infra-red rays, but grow more and more considerable for the shorter wave lengths. Pettit, indeed, observing with the narrow band of ultra-violet rays which silver transmits, centering at 3,160 Angstroms, finds alterations of over 100 per cent in their intensity. This means that if our eyes were sensitive to such rays alone we should find the sun's surface twice as bright at some times as at others.

Other solar phenomena exhibit interesting variations. Nearly 20 years ago Hale discovered magnetism in sun spots, and later over the sun's whole surface. Sun spots are apt to go in pairs, and Hale finds that if the advancing spot of a pair is a north pole in the northern solar hemisphere, it will be a south pole which leads in a spot pair in the southern hemisphere. But this state of things endures only through one 11-year sun-spot cycle. In the following cycle these polarities reverse, so that 22⅓ years are required to bring back the magnetic conditions to the starting point. Bjerknes has proposed an ingenious hypothesis to account for sun spots, their coolness, their going in pairs, the opposite magnetic polarity of the pair, and the reversal of polarity at each 11-year cycle. It depends on hydrodynamic principles and explains the phenomena as due to causes residing within the sun, not to gravitational influences of the planets.

It is well known that terrestrial magnetism reacts to solar activity, and so does the aurora as well. Bauer has shown that the earth's magnetic state marches closely with the intensity of solar radiation as measured by the Smithsonian Institution. Very recently Austin has found that the reception of long-range radio signals also marches hand in hand with the intensity of solar radiation.

The weather, too, so important to human concerns, seems to be affected by solar changes. The importance of this effect is still in controversy, so that I shall not stress it, but merely remark that time will tell. However, I must point out that the solar variation, though obviously associated with the 11-year sun-spot cycle, has hitherto seemed irregular, and therefore unpredictable. But now there seem to appear definite periodicities of 25⅔, 15, and 11 months, and certain harmonics of these periods, which, together with the 11-year period seem to make up the whole long-interval solar variation. If these definite periodicities should persist, we shall be in position to forecast for years in advance the principal solar variation and everything which may be found to depend upon it.

I should give but a feeble impression of the importance of sunlight to life if I should stop at this point. All plants grow by absorbing solar energy and using it to promote chemical reactions in a way still inimitable by chemists. Ultra-violet rays, too, produce certain changes of chemical structure in fats and oils which are the source of those traces of hormones so extraordinarily important, all out of proportion to their infinitesimal occurrence, in the growth and health of animals. The more searching study of the solar spectrum in its relations to these extraordinary chemical reactions is a most fascinating field.

On the grosser side the application of solar energy to power production also offers an attractive research field. Some are disposed to think this chimerical. There are, however, certain lines of improvement over former attempts at the utilization of solar rays directly for power which, I am inclined to think, will solve the problem commercially.—*C. F. B.*

The distribution of mean annual maxima and minima of temperature over the globe.—Dr. C. E. P. Brooks and Miss G. L. Thorman, in Geophysical Memoir, No. 44 (British Meteorological Office, 1928), present isothermal charts of the mean annual maxima and minima, and tables of the means for stations in each 10 degrees of latitude, an arrangement like that of the Reseau Mondial. The charts and tables are based upon data for the years 1910 to 1921. The authors felt that a temperature record of this sort was needed for two main reasons—first, because the mean extremes give an idea of the temperature conditions to be met, roughly speaking, one year in two. And secondly, in order to minimize the possible instrumental error in recording absolute maxima or minima. Mean extremes also are, for different periods, more nearly comparable than the absolute extremes. In plotting the data no correction was made for the height of the station above sea level, because, where the variation of the mean annual maxima and minima with height was investigated at several stations in the western United States, India, and Switzerland, no regular decrease with height was found, similar to that which exists in mean tempera-

tures. The results indicate that in the case of mean annual maximum temperatures continentality has a greater effect than latitude, whereas in the case of mean annual minimum temperatures, latitude is of equal importance with continentality.—*N. H. B.*

Some remarkable features of the Gulf Stream, by P. Idrac (Comptes Rendus des seances de l'Academie des Sciences, Tome 188, No. 9, p. 644).—These studies were made this winter (1928–9) in the Florida Strait during the course of oceanographic researches assigned to me by Monsieur Claude in view of the installation on the coasts of Cuba of the first Claude-Boucherot works utilizing the thermal energy of the sea.

As is well known, the Gulf Stream is a warm current which, after being formed in the Gulf of Mexico, escapes toward the Atlantic Ocean through the passage about 70 miles wide and 1,000 to 1,800 meters deep separating Cuba from the reefs west of the point of Florida.

For four different dates in a period of three months I was able to construct thermal cross sections of the strait, each obtained from some 50 measurements to a depth of 1,000 meters well distributed over the whole extent of the strait, each of these measurements being checked by the simultaneous reading of two upsetting thermometers.

Some simultaneous measurements of the current were made from the surface to a depth of 1,400 meters by means of the recording apparatus for velocity and direction described in an earlier paper (Courants sousmarins de Gibraltar, Comptes Rendus, 186, 1928, p. 1058). The drift of the boat was reckoned from bearings of the land. The effect of the wind and the swell was eliminated by plunging the apparatus some meters below the surface, which gave the proper drift of the boat relative to the surface current. The apparatus was then lowered to different depths to obtain the velocity of the deep current relative to the drift of the boat, whence there could be deduced by a simple graph the actual velocity of the deep current.

Better than all explanations the figures give an idea of the structure of the Gulf Stream and of the rapid thermal variations which can in certain cases amount to more than 5° C. in five days.

Fortunately for the project of Monsieur Claude all of this variability fades out much below the depth of 800 meters, which appears scarcely touched by the Gulf Stream except when it is very strong. At 1,000 meters, for example, there is almost uniformly a temperature of 5° C. in the entire length of the channel.

The bulk of the current is generally nearer to the coast of Cuba than to the Florida Keys. It approaches or recedes, it seems, in a rather irregular manner, but in a manner that is without doubt connected with the extent of the cold current from Labrador, which extends, as is seen in the figures, along the coast of Florida, where it gives, at equal depth, lower temperatures than those on the Cuban coast.

At the surface the axis of the current of the Gulf Stream generally coincides roughly with the axis of the highest temperatures (yet when the Gulf Stream recedes from the Cuban coast the surface in that vicinity remains warm). Each time that we were able to make measurements we found that in the depths the axis of the current did not coincide with the vertical axis of the surface current and was plainly shifted toward the Cuban coast.

Where it is strongest (having a velocity of 3 knots in the period of our measurements) the current remains rather constant from the surface to a depth of 300 meters and then gradually weakens. Sometimes there are still found currents of 1 knot at the depth of 500 meters and of 0.5 knot at the depth of 1,000 meters.

From the results obtained there can be deduced the approximate discharge of the Gulf Stream. This, too, is very variable; for example, it was of the order of 50 cubic kilometers per hour on December 1, 1928, but amounted to about 90 cubic kilometers per hour on January 31, 1929.

Without doubt it would be interesting in the general study of the currents of the Atlantic Ocean and, perhaps, even of the climatic variations of western Europe to make periodic measurements of the discharge of this mighty river of warm water.

The first four figures (not reproduced) represent the thermal cross sections, on different dates, of the Strait of Florida between Havana and the Florida Keys. There will be noted, among other things, the rapidity of variation between November 26 and December 1, 1928.

The last figure shows the form of the current of the Gulf Stream off Havana. The heavier the shading, the stronger the current. The prolongation of the beds of the deep current toward Havana appears to be due to the influence of the cold current coming from Labrador and skirting the coast of Florida in the depths.—*Translated by W. W. Reed.*

Early meteorological observations in northern Michigan.—We are indebted to Nathan C. Rockwood, editor-manager of Rock Products of Chicago, Ill., for nine months meteorological observations made at Michilimackinac, Mich. (present Mackinac), by Captain Dunham from August, 1802, to April 1803, both inclusive. The observations came into Mr. Rockwood's possession through his great-grandfather William Dandridge Peck, professor of natural history at Harvard and an early American scientist. The observations were made three times daily at sunrise, noon, and sunset. The mean temperature has been computed by taking one-third of the sum of the means for the times mentioned, the resulting means being quite close to those that would be obtained from the daily extremes.

The temperatures recorded by Captain Dunham do not differ greatly from those made at Cheboygan, Mich., a short distance from Mackinac, in more recent times—the summary as prepared by the Climatological Division of the Weather Bureau follows.—*A. J. H.*

Summary of meteorological observations at Michilimackinac (Mackinac), Mich., from August, 1802, to April, 1803, both inclusive

	Temperature																
	Mean [1]	Maximum	Minimum	Mean Maximum	Mean Minimum	Range				Days with precipitation	Days with snow	Days with thunderstorms	Days with fog	Clear	Partly cloudy	Cloudy	Wind—prevailing direction
						Mean daily	Greatest	Least	Absolute								
1803																	
January	13.3	36	−14	16.5	9.2	7.2	20	0	50	8	8	0	0	17	3	11	W.
February [2]	17.7	50	−24	24.4	9.8	14.8	34	2	74	1	1	0	0	24	0	3	S.
March	25.2	49	−10	30.3	19.4	10.9	24	0	59	8	3	0	4	17	2	12	W.
April	39.4	59	20	45.4	33.2	12.2	30	1	39	12	3	1	0	14	5	11	E.
1802																	
August	67.4	83	36	71.9	62.1	9.7	32	2	47	7	0	3	4	23	1	7	SW.
September [3]	61.8	73	40	65.9	57.5	8.9	26	2	33	6	0	1	1	19	4	6	N.
October	51.0	72	30	55.4	46.5	8.6	18	2	42	9	2	0	2	11	2	15	N.
November	41.9	60	29	44.2	39.4	4.9	15	1	31	7	3	0	4	10	1	19	S.
December [4]	21.0	49	−11	24.0	17.5	6.6	15	0	60	7	7	0	1	16	2	12	N.

[1] Mean of 3 observations, sunrise, noon, and sunset. [2] Record for 27 days. [3] Record for 29 days. [4] Record for 30 days.

Measurement and determination of magnitude of cooling. (*By Dr. V. Conrad, Vienna, reprinted from Gerlands Beiträge zur Geophysik Vol. XXI, Part 2/3, 1929.*)—Summary: From January to April, 1928, observations with L. Hill's katathermometer were being made at the sanatorium Grafenhof (Salzburg). Synchronous measures of air temperature and wind velocity (with the anemometer) allowed a comparison between the cooling power observed with the Kata (H) and calculated out of the wind velocity and air temperature with Doctor Hill's formula (h). The investigation shows: (1°) That the quotient H/h is very little influenced by the air temperature; (2°) that there is a functional connection between the value of H/h and the wind velocity. Within certain bounds, given by the present observations it is possible to express the mentioned connection analytically. The size of H/h reaches values >2 at very little velocities and becomes nearly constant (0.9) at velocities >1 m/s. If the conclusions drawn from the present material hold, it will be possible to calculate the cooling power in mgcal/cm², sec. out of wind velocity and air temperature (for velocities >1 m/s) with Hill's formula slightly corrected.

Tornado, May 1, 1929, at Fort Smith, Ark. (By Truman G. Shipman).—The morning weather map of May 1, 1929, showed a troughlike barometric depression extending from the Rio Grande Valley northeast across the middle Lakes region. A pressure reading of 29.48 inches was reported at Abilene, Tex. An extensive HIGH covered the western portions of the United States with a pressure reading of 30.36 inches at Boise, Idaho. Sharp drops in temperature and steep temperature gradients were noted over western Texas and the southern Rockies. A rather well defined line of opposing winds appeared near the center of the trough. The P. M. map showed much the same conditions moved eastward with a low pressure reading of 29.38 inches over Little Rock, Ark. The morning map of May 2, 1929, published at Washington, D. C., showed that the southern center of the depression moved about 1,250 miles in 24 hours or about 52 miles an hour.[1] This is considerably less than the velocity of the tornado as it passed over Fort Smith.

Telephone calls and weather conditions indicated the presence of a tornado at 2:30 p. m. The beginning of the tornado could not be seen from the office as it approached from the opposite side of the building. An attempt was made, but given up to reach the roof at this time. After the storm had passed northeast of the building, two office employees ascended to the roof and saw the tornado cloud over Sand Prairie, Crawford County.

The tornado formed in Oklahoma and was observed by a bus driver along the Fort Smith-Gore Highway. It was also observed at Peno, Okla., about 4 miles west of Fort Smith. It almost followed the path of the tornado that struck Fort Smith, May 28, 1924, and seemed to be high in the air as that storm was. The first funnel cloud observed in Fort Smith appeared where Wheeler Avenue crosses the Missouri Pacific tracks where it hit the Fort Smith Handle Co.'s plant. This cloud was described as a ropelike or serpentlike formation swaying in the air, but rather clear and distinct. The heaviest damage was inflicted here and along a path about one-fourth to one-half mile to the east. The second tornado cloud was shaped like a sheaf and was wide and less distinct. The third cloud was an inverted cone which did not reach the ground but formed immediately after the second. The storm then seemed to pass almost entirely over the city doing only light, scattered damage until its reached Sand Prairie, Crawford County, about 8 miles distant. This tornado cloud was observed by the employees of the office from the roof of the Federal Building in Fort Smith at 2:37 p. m. The cloud was shaped like an inverted truncated cone, rather wide and poorly defined and its outlines somewhat dimmed by light rains. The tornado had traveled 8 miles in 7 minutes at about 69 miles an hour which is close to the extreme wind velocity as recorded at the Weather Bureau office. In general the path was slightly north of east and very narrow. The nearest part of the path lay about 1¼ miles southeast of the office building.

Before the arrival of the first funnel-shaped cloud in Fort Smith at Wheeler Avenue and to the right and in the rear of where the cloud formed, an educated and reliable observer reported rain descending in sheets, clouds seemed to be boiling over and between the sheets of descending rain, an open space. He interpreted this as a wide, sheaf-shaped vortex without the cloud sheet leaving it transparent.

At a few times in the path of this tornado, what appeared to be explosive effects accompanied by vapor were seen and reported by observers, including Mr. Baughman of the Weather Bureau office. These observations are quite interesting and would indicate that the temperature in the tornado funnel varied during its progress, ranging from slightly below to slightly above the dew point. The thermograph at the Weather Bureau office, 1¼ miles distant, showed a temperature of 66° (fig. 1) at the time of the tornado and a dew point of 63° was observed at a special observation at 2:50 p. m.

[1] It is preferred to believe that there was a rise in pressure in the southern end of the trough which would automatically transfer the center to the north, rather than that there was an actual progression of the southern center.—ED.

Portions of transparent tornado funnels have been reported frequently and have been observed by the writer in another storm. Storms are frequently observed in Fort Smith that approach tornadoes and may have invisible vortices. Clouds show boiling effects, parallel opposing currents and vortices. The details of clouds in these storms are quite distinct showing striated effects, clouds moving in echelon, and mammato-cumulus forms are seen.

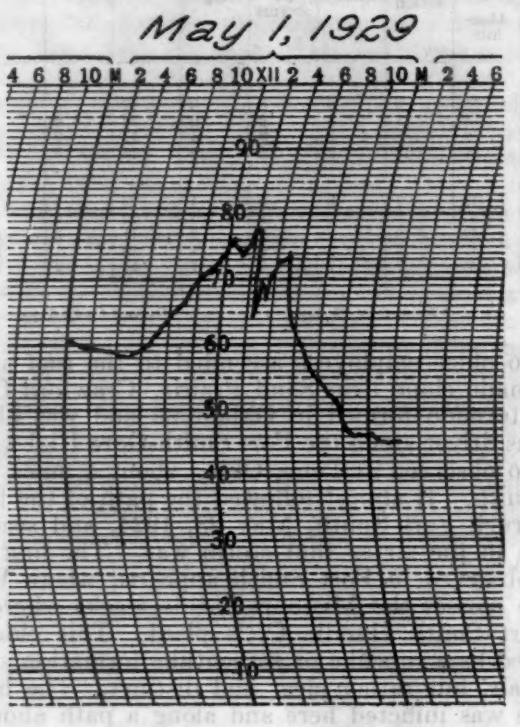

FIGURE 1.—Thermograph trace, Fort Smith, Ark., May 1, 1929

Tornado clouds are formed by the cooling of the air below the dew point by expansion incident to the decrease of pressure caused by rapid whirling.

It is interesting to note the chronological order of appearance of tornado cloud forms. The ascending currents without the outside cloud sheet, producing boiling effects and scud are the first to appear. The earlier funnels are usually thin, ropelike, and rather sharply defined like moisture condensing on the outside of a cold vessel. This condition lasts only a very short time as the cloud sheet rapidly thickens to a cone-shaped funnel. If this goes on further, rain falls and the funnel cloud is obscured or may disappear on account of diminishing intensity of the whirl.

The barograph during the storm of May 1 showed a pressure of 0.14 inch (fig. 2) during the two hours preceding, a fall of 0.09 inch during the storm, and a rise of 0.11 immediately after it. The lowest reading was 29.23 inches. Temperature showed a drop of 13° during the storm's passage. Unfortunately the wind partially failed to record and only a partial record was obtained. The maximum velocity as near as could be computed was 62 miles an hour and the extreme 74 miles. The velocity of the tornado was near the extreme velocity. The wind shifted 180° in one minute during the passage of the tornado. Practically all directions were represented by cloud and surface wind movements during the day. Opposing currents were observed in clouds during storm and an imposing display of cumulo-nimbus was observed immediately afterwards.

An interesting feature occurred in connection with the Fort Smith Handle Factory damage. The side walls of this building were blown outward as the funnel cloud passed, but the roof was not blown upward. The roof had a ventilating stack extending upward that relieved the upward pressure. Houses damaged in other parts showed roofs blown upward.

The damage in Fort Smith was light. Fortunately the storm was high in the air and it struck only one edge of the city with any degree of force. The damage in Fort Smith was estimated at $25,000. Five persons were hurt at Fort Smith and seven at Sand Prairie, Crawford County.

At 3:30 p. m. of the same day, Rex, a village 98 miles slightly north of east of Fort Smith was wiped out by a tornado. Two persons were seriously hurt and four received lighter injuries. The damage to this village was estimated at $40,000. Typical tornado clouds and conditions were reported. It was first thought this was the tornado that struck Fort Smith as it lies in the same direction of progress, but 98 miles an hour seems a rather high velocity for a tornado.

Severe hailstorm at Springfield, Ill., May 1, 1929. By C. J. Root).—A severe hail storm occurred in southern Illinois on the afternoon of May 1. It covered a strip varying from 2 to 6 miles in width and extended across Williamson and parts of Jackson and Saline Counties.

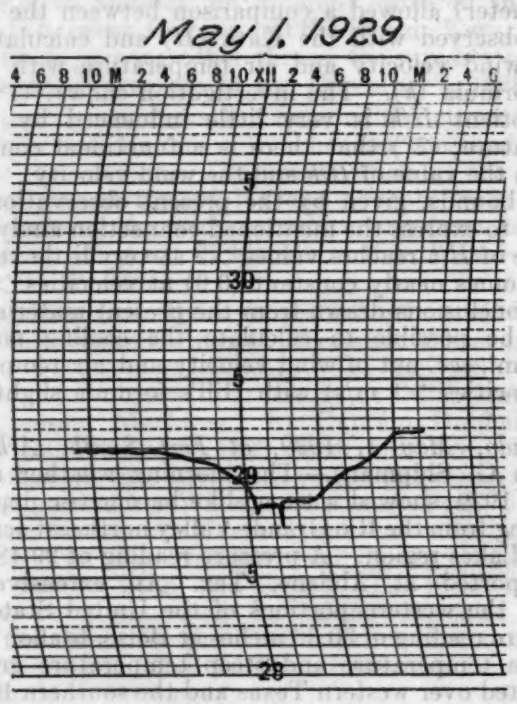

FIGURE 2.—Barograph trace, Fort Smith, Ark., May 1, 1929

Near the south edge of the path hail fell to a depth of several inches, the stones being about the size of marbles. At the Marion cemetery, at the north edge of Marion the writer saw the entire cemetery group of trees entirely denuded of foliage and having the appearance of midwinter. Shrubbery and small limbs were badly barked. Farther north the stones were larger but more scattered, causing less damage to vegetation but more to property. Stones were reported up to the size of hen eggs, and there were numerous instances of roofs and automobile tops being punctured. The losses will total several hundred thousand dollars.

Progressive desiccation in southwest Africa.—The late Prof. E. H. L. Schwarz, during his 10 year's work on the Geological Survey of Cape Colony, realized the extent to which some parts of the country had been impoverished

by drought. He devoted himself to the question of how this alarming process could be checked, and in 1918 published his well known scheme for the diversion of water from the Zambesi into the great depressions of Lake Ngami and the Kalahari.

In 1925, while on the Kalahari reconnaissance expedition, sent by the Government to investigate his proposals, Professor Schwarz found the country suffering from floods and he returned by canoe from the Victoria Falls to Lake Ngami, which was reoccupied by water, * * * Professor Schwarz has just published an account of his journeys in this region. In his book he says "A country that had resigned itself to a condition of permanent drought was for a time gladdened by the sound of rippling water on all sides." The book also contains a summary of the condition of Lake Ngami as follows: 1760, dry; 1813 to Livingston's visit in 1849, a great lake that had already begun to decline; 1854–1864, some shallow water surrounded by reeds; 1896–1922, no water, lake bed a dry plain; 1925 lake reoccupied by water.—*Reprinted from Nature, February 2, 1929.*

Snow cover in eastern Siberia.—W. B. Shostakovitch summarizes the snowfall in eastern Siberia as follows: Measurements have been made daily at 7 a. m. since 1881. Up to 1913 they had been made at 231 stations, only about 37 per cent of them, however, have so long a series as 5 years. The thickness of the snow cover, while it shows good correlation with precipitation, depends as well upon many other elements, such as air temperature, wind, evaporation, etc. February is the month of maximum snowfall. The depth in that month ranges from 10 to 100 centimeters (3.9 to 39 inches). Topographic features exert a great influence upon the accumulation of snow. On the windward slopes of mountains where the precipitation is heavy, the depth of snow increases considerably; on leeward slopes it decreases sharply. A snow sheet covers the ground from 25 to 70 days in the seaside district northeast of the Sea of Okhotsk and attains to 250 to 259 days in the extreme north regions. Almost all eastern Siberia lies under an uninterrupted snow cover during more than 150 days, the duration gradually increasing with latitude.

Meteorological summary for Chile, April, 1929. (By J. Bustos Navarrete, Observatorio del Salto, Santiago, Chile.)—Atmospheric circulation had moderate intensity during the month of April. In the central zone lack of precipitation continued, while in the southern zone there was normal intensity of rainfall.

The chief depressions, bringing foul weather and rain in the south, were those of the 1st–2d and 6th, crossing the extreme south, and, most important, that of the 20th causing general rains as far as Talca.

Periods of fine weather accompanied anticyclonic centers charted as follows: 7th–9th, in the southern region; 17th–18th, moving from Juan Fernandez to Chiloe; 25th–28th, advancing from southern Chile to the central part of northern Argentina.

The total monthly precipitation was 0.75 inch to 1.20 inches in the region of Concepcion and around 8 inches in region of Valdivia.—*Translated by W. W. R.*

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SOLAR OBSERVATIONS

SOLAR RADIATION MEASUREMENTS DURING MAY, 1929

By HERBERT H. KIMBALL

For reference to descriptions of instruments and exposures, and an account of the method of obtaining and reducing the measurements, the reader is referred to this Volume of the REVIEW, page 26.

Table 1 shows that solar radiation intensities averaged slightly below normal values for May at all three stations at which measurements are made.

Table 2 shows a deficiency in the total radiation received on a horizontal surface at Lincoln, as compared with the May normal, and an excess at Washington, Madison, Chicago, and New York.

Skylight polarization measurements obtained on six days at Washington give a mean of 51 per cent with a maximum of 60 per cent on the 7th. These are close to the corresponding averages for May at Washington. At Madison measurements obtained on nine days give a mean of 54 per cent, with a maximum of 63 per cent on the 7th. These are only slightly below the corresponding average for May at Madison.

TABLE 1.—*Solar radiation intensities during May, 1929*

[Gram-calories per minute per square centimeter of normal surface]

Date	Sun's zenith distance									
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass									Local mean solar time
		A. M.					P. M.				
	c.	5.0	4.0	3.0	2.0	[1]1.0	2.0	3.0	4.0	5.0	c.
	mm.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*mm.*
Washington, D. C.											
May 7	7.87					1.33	1.09	0.90	0.71		6.02
May 8	3.99			0.81	1.03	1.20					4.37
May 10	3.99				0.94	1.27	0.93	0.72	0.56	0.46	4.57
May 16	14.10				0.99						15.11
May 17	3.81	0.74	0.85	1.03	1.20	1.38					3.99
May 22	7.29		0.62	0.77	0.99	1.23	0.92				3.30
May 23	7.87			0.71	0.86	1.19					6.27
May 27	12.24				0.59						16.79
May 31	16.79			0.47	0.73						16.79
Means		(0.74)	(0.74)	0.76	0.92	1.27	0.98	(0.81)	(0.64)	(0.46)	
Departures		+0.10	+0.03	−0.05	−0.06	−0.01	−0.01	+0.02	−0.02	−0.12	
Madison, Wis.											
May 4	3.15			1.01	1.20	1.42					4.37
May 7	3.15				1.23	1.44					8.63
May 9	4.37		0.67	0.86	1.09	1.34					3.00
May 15	11.81				1.04	1.34					15.11
May 16	3.81				1.06	1.34					3.30
May 19	3.45				1.20						3.99
May 20	3.30					1.36					2.62
May 21	5.16				1.07						5.56
May 22	15.65				1.00	1.26					5.36
May 24	6.76				1.10	1.28					4.75
May 25	5.79				0.98	1.20					8.48
Means			(0.67)	(0.94)	1.10	1.33					
Departures			−0.23	−0.01	−0.01	−0.03					
Lincoln, Nebr.											
May 2	3.45			1.11	1.22	1.49					3.45
May 13	7.87				0.76						7.04
May 14	8.81					1.37	1.13	0.96			11.38
May 15	13.61						1.15	0.94	0.80		5.79
May 16	4.37		0.91	1.01	1.20	1.41					3.81
May 21	7.29			0.68	0.93	1.27					7.04
May 24	8.48				0.88						12.24
May 25	10.97			0.91	1.08	1.28					10.59
Means			(0.91)	0.93	1.01	1.36	(1.14)	(0.95)	(0.80)		
Departures			+0.10	−0.01	−0.11	−0.02	+0.03	+0.02	+0.01		

[1] Extrapolated.

TABLE 2.—*Solar and sky radiation received on a horizontal surface*

[Gram-calories per square centimeter or horizontal surface]

Week beginning—	Average daily radiation							Average daily departure from normal				
	Washington	Madison	Lincoln	Chicago	New York	Twin Falls	Fresno	Washington	Madison	Lincoln	Chicago	New York
1929	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
Apr. 30	339	463	414	154	274	646	724	−111	+11	−66	−201	−79
May 7	564	467	421	365	453	626	685	+107	−1	−66	−12	+99
May 14	425	471	588	448	318	[1]823	614	−38	−2	+73	+64	−53
May 21	554	494	495	466	432	[1]745	713	+72	+10	−33	+64	+35
May 28	545	581	321	432	432	....	742	+46	+94	−205	+15	+8
Excess or deficiency since first of year on June 3								−665	−1,057	−698	+1,029	−2,758

[1] 6-day mean.

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. C. S. Freeman, Superintendent U. S. Naval Observatory. Data furnished by Naval Observatory, in cooperation with Harvard, Yerkes, and Mount Wilson Observatories. The differences of longitude are measured from central meridian, positive west. The north latitudes are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, including spots and groups, is given for each day in the last column]

Date	Eastern standard civil time	Heliographic			Area		Total area for each day
		Diff. long.	Longitude	Latitude	Spot	Group	
1929	h. m.	°	°	°			
May 1 (Naval Observatory)	12 20	−63.0	64.8	+12.5	15	.....	.....
		−40.5	87.3	−21.0	.....	123	.....
		−34.0	93.8	−8.5	.....	231	.....
		−25.5	102.3	−1.0	.....	231	.....
		+9.0	136.8	+14.5	.....	77	677
May 2 (Naval Observatory)	11 33	−51.0	64.0	+12.5	.....	34	.....
		−47.5	67.5	−6.5	.....	9	.....
		−28.0	87.0	−21.0	.....	185	.....
		−21.0	94.0	−8.5	.....	216	.....
		−12.0	103.0	−1.0	.....	216	.....
		+22.0	137.0	+14.5	.....	68	728
May 3 (Naval Observatory)	11 43	−69.5	32.2	−21.0	6	.....	.....
		−37.0	64.7	+12.5	.....	25	.....
		−14.0	87.7	−21.0	.....	154	.....
		−7.0	94.7	−8.0	.....	262	.....
		−2.5	99.2	+16.0	.....	25	.....
		+2.0	103.7	−1.5	.....	247	.....
		+34.5	136.2	+15.0	37	.....	756
May 4 (Naval Observatory)	11 15	−52.0	36.7	−21.0	6	.....	.....
		−1.0	87.7	−20.0	.....	37	.....
		+6.0	94.7	−8.5	.....	216	.....
		+12.5	101.2	+16.0	.....	93	.....
		+16.5	105.2	−1.5	.....	231	.....
		+47.5	136.2	+14.0	31	.....	614
May 5 (Naval Observatory)	14 12	−68.0	5.9	+16.5	77	.....	.....
		+21.5	95.4	−9.0	.....	201	.....
		+26.0	99.9	+15.5	.....	216	.....
		+31.0	104.9	−1.0	.....	247	.....
		+61.5	135.4	+14.5	25	.....	766
May 6 (Naval Observatory)	11 8	−74.5	347.9	+3.5	62	.....	.....
		−69.5	352.9	+6.5	6	.....	.....
		−56.5	5.9	+16.0	.....	77	.....
		+33.0	95.4	−9.0	.....	139	.....
		+38.0	100.4	+15.5	.....	278	.....
		+43.5	105.9	−1.5	.....	231	793
May 7 (Naval Observatory)	11 41	−61.0	347.8	+4.5	93	.....	.....
		−39.5	9.3	+16.0	46	.....	.....
		−37.0	11.8	+9.0	6	.....	.....
		−27.0	21.8	−9.5	.....	46	.....
		+41.5	90.3	−18.5	.....	77	.....
		+46.5	95.3	−9.5	.....	123	.....
		+52.0	100.8	+15.5	.....	262	.....
		+57.0	105.8	−1.0	.....	231	884
May 8 (Naval Observatory)	11 31	−76.5	319.2	+5.5	185	.....	.....
		−46.5	349.2	+4.0	77	.....	.....
		−26.5	9.2	+15.5	.....	62	.....
		−12.5	23.2	−9.5	.....	77	.....
		+61.5	97.2	−8.5	.....	154	.....
		+65.5	101.2	+16.5	.....	170	.....
		+70.5	106.2	−0.5	.....	247	972
May 8 (Naval Observatory)	15 31	−74.0	319.5	+5.0	185	.....	.....
		−71.5	322.0	−5.5	46	.....	.....
		−44.5	349.0	+4.0	46	.....	.....
		−24.5	9.0	+15.5	.....	77	.....
		−10.0	23.5	−9.5	.....	77	.....
		+57.0	90.5	−17.5	.....	66	.....
		+63.0	96.5	−8.5	.....	139	.....
		+66.0	99.5	+16.5	.....	231	.....
		+72.0	105.5	−0.5	.....	216	1,083

Positions and Areas of Sun Spots—Continued

Date	Eastern standard civil time	Heliographic			Area		Total area for each day
		Diff. long.	Longitude	Latitude	Spot	Group	
1929	h. m.	°	°	°			
May 9 (Naval Observatory).	13 15	−62.5	319.0	+5.0	185		
		−59.0	322.5	−6.0	15		
		−32.0	349.5	+4.5	46		
		−11.0	10.5	+15.0	62		
		+2.0	23.5	−10.0		93	
		+76.5	98.0	−8.5		108	
		+76.5	98.0	+8.5	108		617
May 10 (Naval Observatory).	11 39	−48.5	320.7	+4.5	201		
		−19.0	350.2	+4.0	46		
		+0.5	9.7	+15.5		123	
		+14.5	23.7	−9.5		123	493
May 11 (Naval Observatory).	11 42	−49.0	306.9	+4.5	3		
		−36.0	319.9	+4.5	185		
		−6.0	349.9	+4.0	46		
		+13.5	9.4	+14.5		123	
		+27.0	22.9	−11.0		139	
		+44.0	39.9	+9.0		22	518
May 12 (Naval Observatory).	11 31	−22.5	320.3	+5.0	185		
		+8.0	350.8	+4.0	46		
		+29.0	11.8	+14.5	108		
		+41.0	23.8	−10.0		340	679
May 13 (Mount Wilson).	9 30	−78.0	252.8	−5.0	45		
		−45.0	285.8	−13.0		8	
		−10.0	320.8	+4.0		254	
		+20.0	350.8	+4.0		50	
		+30.0	0.8	−10.0		8	
		+42.0	12.8	+14.0	152		
		+54.0	24.8	−10.0		449	966
May 14 (Naval Observatory).	11 57	−68.5	247.6	+21.0	9		
		−60.5	255.6	−5.0	62		
		+4.5	320.6	+5.0	185		
		+34.5	350.6	+4.0	31		
		+55.0	11.1	+14.5		123	
		+68.0	24.1	−10.0		463	873
May 15 (Naval Observatory).	11 58	−56.5	246.4	+21.0		46	
		−56.0	246.9	+11.0	15		
		−47.0	255.9	−5.5	31		
		+18.0	320.9	+5.0	185		
		+48.0	350.9	+4.0	31		
		+62.0	4.9	−8.5	9		
		+68.0	10.9	+14.5		170	
		+83.0	25.9	−9.5		664	1,151
May 16 (Naval Observatory).	13 16	−43.0	246.0	+11.5		46	
		−42.5	246.5	+21.5	12		
		−33.0	256.0	−5.0	15		
		−22.0	267.0	+10.5	15		
		+32.0	321.0	+5.5	170		
		+62.5	351.5	+4.5	25		
		+83.0	12.0	+14.5	185		468
May 17 (Naval Observatory).	11 40	−31.0	245.6	+21.5	15		
		−30.0	246.6	+11.0		62	
		−20.5	256.1	−5.0	25		
		−9.0	267.6	+10.5		93	
		+45.0	321.6	+5.0	154		
		+74.0	350.6	+4.5	31		380
May 18 (Naval Observatory).	11 33	−18.5	244.9	+21.0	12		
		−18.0	245.4	+11.5		31	
		−8.5	254.9	−5.5		46	
		+4.5	267.9	+10.0		77	
		+58.0	321.4	+5.0	123		289
May 19 (Naval Observatory).	11 41	−4.0	246.1	+11.5		62	
		+4.0	254.1	−7.0	9		
		+18.5	268.6	+10.0		62	
		+38.5	288.6	−10.0		22	
		+71.0	321.1	+5.0	123		278
May 20 (Mount Wilson).	13 15	+11.0	247.1	+10.0		20	
		+33.0	269.1	+10.0		15	
		+85.0	321.1	+4.0	147		182
May 21 (Naval Observatory).	12 24	+23.5	246.8	+11.0		46	
		+47.0	270.3	+11.5		37	83
May 22 (Naval Observatory).	11 43	−75.5	134.9	+13.5	262		
		+36.0	246.4	−4.5	6		
		+37.5	247.9	+11.5		37	
		+47.0	257.4	+6.5	3		308

Positions and Areas of Sun Spots—Continued

Date	Eastern standard civil time	Heliographic			Area		Total area for each day
		Diff. long.	Longitude	Latitude	Spot	Group	
1929	h. m.	°	°	°			
May 23 (Naval Observatory).	11 41	−64.0	133.2	+13.5		586	
		−34.5	162.7	+20.5		15	
		+50.5	247.7	−6.0		31	
		+55.0	252.2	+12.5	25		657
May 24 (Naval Observatory).	11 51	−76.0	107.9	+15.0	15		
		−52.0	131.9	+13.0		540	
		−21.0	162.9	+20.5		123	
		+63.5	247.4	−6.0	22		700
May 25 (Naval Observatory).	11 38	−74.5	96.3	+17.5	93		
		−62.5	108.3	+14.5	28		
		−38.0	132.8	+13.5		525	
		−7.0	163.8	+21.0		231	
		+17.0	187.8	+11.0		25	
		+34.5	205.3	+15.0	6		
		+80.5	251.3	−6.5		62	970
May 26 (Naval Observatory).	11 20	−60.5	97.2	+17.5	77		
		−48.5	109.2	+14.5	6		
		−22.5	135.2	+13.5		463	
		+6.5	164.2	+21.5		185	
		+48.5	206.2	+14.5		31	762
May 27 (Naval Observatory).	11 45	−47.0	97.3	+17.5	62		
		−35.0	109.3	+14.5	3		
		−8.5	135.8	+14.0		448	
		+21.0	165.3	+21.0		123	636
May 28 (Naval Observatory).	12 1	−33.5	97.4	+17.0	46		
		+5.5	136.4	+14.5		355	
		+35.0	165.9	+21.5		401	802
May 29 (Harvard).	12 7	−21.0	96.5	+17.5		67	
		+11.5	129.0	+13.0	78		
		+19.0	136.5	+15.0		520	
		+41.5	159.0	+20.0		22	
		+52.0	169.5	+22.0	82		769
May 30 (Naval Observatory).	11 16	−7.5	97.3	+17.0		46	
		+31.5	136.3	+14.5		324	
		+63.5	168.3	+21.5	15		385
May 31 (Naval Observatory).	11 18	−86.0	5.6	+13.5		93	
		+6.0	97.6	+17.0		46	
		+6.5	98.1	−12.0	9		
		+45.0	136.6	+14.5	370		518
Mean daily area for May							636

PROVISIONAL SUN-SPOT RELATIVE NUMBERS FOR MAY, 1929

[Data furnished through the courtesy of Prof. W. Brunner, University of Zurich, Switzerland]

May, 1929	Relative numbers	May, 1929	Relative numbers	May, 1929	Relative numbers
1	[1] 65	11	52	21	30
2	94	12	48	22 [4]	34
3	M [2,3] 88	13	76	23	30
4	[1] 74	14	[1] 71	E [3] 24	49
5	74	15	73	25	61
6	83	16	E [2,3] 73	26 [1]	59
7	E [3] 71	17	53	27	59
8	[4] 79	18	[1] 47	28 [2]	59
9		19	28	29	35
10	[1,1] 62	20	[1] 32	30	35
				31	34

Mean, 30 days: 57.6.

[1] Passage of an average-size group through the central meridian.
[2] Passage of a large group through the central meridian.
[3] New formation of a large or average-sized center of activity: E, on the eastern part of the sun's disc; W, on the western part; M, in the central zone.
[4] Entrance of a large or average-sized center of activity on the east limb

AEROLOGICAL OBSERVATIONS

By L. T. SAMUELS

Free-air temperatures for the month were below normal except at the eastern stations, Due West and Washington, the largest negative departures occurring at the northern stations, Ellendale and Royal Center. (See Table 1.)

Relative humidity departures were small except at the higher levels at Ellendale and Royal Center where moderately large negative values occurred.

It will be noted that an abnormal, i. e., inverse, relationship occurs between the temperature and vapor pressure departures in the lower levels at Broken Arrow and Groesbeck. In this connection it is interesting to note that at both of these stations the total monthly rainfall was excessive—Broken Arrow, 7.02 inches, and Groesbeck, 16.59 inches, 0.01 inch, or more occurring on 14 days at both stations.

From Table 2 it will be seen that the resultant wind movement for the month at 3 and 4 kilometers was practically due west over the entire country except over the extreme western and southern sections. A strong northerly component persisted at these levels over the west coast while a large southerly component is found over New Orleans and an easterly over Key West, the latter persisting to 6 kilometers, above which no observations were made. The southerly component over New Orleans disappeared entirely at 6 kilometers, and a due west resultant prevailed to 8 kilometers.

The resultant velocities increased in general with increase in latitude.

Table 3 shows the record for aerological observations during the month. It will be noted that the highest average altitude obtained as well as the highest single flight during the month occurred at Groesbeck, the southernmost station.

TABLE 1.—*Free-air temperatures, relative humidities, and vapor pressures during May, 1929*

TEMPERATURE (°C.)

Altitude m. s. l.	Broken Arrow, Okla. (233 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Groesbeck, Tex. (141 meters)		Royal Center, Ind. (225 meters)		Washington, D. C. (Naval air station) (7 meters)	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Meters												
Surface	18.7	−1.0	19.5	−0.8	11.1	−2.0	20.7	−1.8	13.8	−2.3	19.9	+1.6
500	16.4	−1.4	17.1	−0.6	10.5	−2.2	18.4	−1.4	11.1	−2.3	15.6	+0.5
1,000	14.1	−1.5	14.8	+0.2	7.0	−2.5	16.3	−1.1	7.5	−2.7	13.7	+1.4
1,500	12.2	−1.2	12.3	+0.7	4.2	−2.4	14.8	−0.8	5.4	−2.0	11.7	+2.1
2,000	9.9	−0.9	9.8	+0.9	1.2	−2.4	12.7	−0.7	3.7	−1.3	10.2	+3.0
2,500	7.1	−0.9	7.0	+0.8	−0.9	−1.6	9.7	−1.0	1.7	−0.9	8.4	+3.7
3,000	3.7	−1.2	3.9	+0.7	−2.5	−0.4	5.8	−1.9	−1.4	−1.2	5.1	+3.2
4,000	−2.7	−1.4	------	------	−8.0	0.0	−1.6	−3.0	−8.0	−1.7	------	------
5,000	------	------	------	------	------	------	−8.8	−4.3	−13.9	−1.8	------	------

RELATIVE HUMIDITY (%)

Surface	74	+4	73	+9	59	−1	81	+9	67	+3	65	+1
500	77	+8	75	+10	59	−1	80	+7	68	+4	64	+3
1,000	71	+4	73	+8	57	−2	75	+6	67	+4	60	+1
1,500	64	+2	71	+5	56	−4	60	+2	54	−7	59	−1
2,000	56	−3	66	+3	55	−5	46	−3	41	−16	54	−5
2,500	53	−3	65	+4	47	−12	46	+1	32	−19	46	−10
3,000	57	+3	57	−1	41	−16	54	+9	28	−19	51	−5
4,000	89	+34	------	------	40	−13	53	+7	34	−12	------	------
5,000	------	------	------	------	------	------	55	+2	34	−12	------	------

VAPOR PRESSURE (*mb.*)

Surface	16.53	+0.10	17.08	+1.79	8.36	−0.72	20.29	+0.63	11.44	−0.44	15.98	+2.22
500	14.94	+0.56	15.15	+1.83	8.08	−0.75	17.40	+0.29	9.86	−0.25	12.63	+1.82
1,000	12.05	+0.22	12.78	+1.71	6.26	−0.79	13.99	+0.23	7.79	−0.42	10.62	+1.84
1,500	9.50	+0.18	10.91	+1.67	5.00	−0.89	9.80	−0.30	5.54	−1.04	9.07	+1.51
2,000	6.94	−0.47	8.85	+1.49	3.85	−0.92	6.54	−0.78	3.88	−1.23	7.29	+0.97
2,500	5.31	−0.46	7.47	+1.60	2.60	−1.15	5.46	−0.26	2.66	−1.10	5.54	+0.56
3,000	4.51	−0.07	5.46	+0.90	2.10	−0.81	4.86	+0.13	1.51	−1.19	4.67	+0.65
4,000	4.24	+1.17	------	------	1.95	+0.30	2.89	−0.16	0.34	−1.18	------	------
5,000	------	------	------	------	------	------	2.25	−0.33	------	------	------	------

TABLE 2.—*Free-air resultant winds (meters per second) based on pilot balloon observations made near 7 a. m. (E. S. T.) during May, 1929*

Altitude m. s. l.	Broken Arrow, Okla. (233 meters)		Burlington, Vt. (132 meters)		Cheyenne, Wyo. (1,868 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Groesbeck, Tex. (141 meters)		Havre, Mont. (762 meters)		Jacksonville, Fla. (65 meters)		Key West, Fla. (11 meters)		Los Angeles, Calif. (40 meters)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
Meters	°		°		°		°		°		°		°		°		°		°	
Surface	S 26 E	1.6	S 19 W	3.2	N 48 W	2.3	S 1 E	0.7	N 61 W	0.5	S 27 E	1.9	N 78 E	0.6	S 36 E	0.9	S 72 E	3.7	S 85 E	1.2
500	S 3 E	5.0	S 32 W	5.8			S 52 W	3.0	N 83 W	0.8	S 4 E	6.6			S 6 E	3.0	S 64 E	7.4	S 68 E	1.7
1,000	S 17 W	6.1	S 72 W	6.8			S 79 W	3.4	S 80 W	2.8	S 12 W	7.4	S 16 E	1.0	S 7 E	1.7	S 66 E	7.0	N 63 E	1.8
1,500	S 56 W	4.0	S 77 W	8.0			S 79 W	4.3	S 82 W	4.8	S 28 W	5.6	S 41 W	1.8	S 41 W	2.0	S 68 E	6.0	N 46 W	3.6
2,000	S 82 W	4.1	N 87 W	7.8	N 56 W	3.2	S 79 W	5.4	N 86 W	5.1	S 56 W	3.9	S 89 W	3.0	S 78 W	1.8	S 72 E	5.2	N 63 W	4.2
2,500	N 82 W	3.5	N 84 W	9.0	N 75 W	4.3	S 87 W	5.1	N 82 W	5.6	S 49 W	2.4	N 77 W	4.5	S 57 W	2.4	S 65 E	4.5	N 62 W	5.4
3,000	N 66 W	3.6	N 78 W	10.8	N 76 W	5.4	S 85 W	5.6	N 65 W	8.2	S 86 W	4.4	N 66 W	3.9	S 63 W	2.5	S 76 E	3.7	N 53 W	7.0
4,000	S 82 W	4.2	N 66 W	9.7	N 80 W	4.2	N 62 W	6.0	N 59 W	13.4	S 71 W	4.6	N 76 W	6.0	S 87 W	4.4	N 77 E	4.6	N 52 W	8.6
5,000	N 87 W	7.0			N 76 W	4.6	N 80 W	7.2	N 63 W	15.9			N 71 W	6.3	N 85 W	4.8	N 35 E	2.4		

Altitude m. s. l.	Medford, Oreg. (446 meters)		Memphis, Tenn. (145 meters)		New Orleans, La. (25 meters)		Omaha, Nebr. (313 meters)		Royal Center, Ind. (225 meters)		Salt Lake City, Utah (1,280 meters)		San Francisco, Calif. (60 meters)		Sault Ste. Marie, Mich. (198 meters)		Seattle, Wash. (67 meters)		Washington, D. C. (34 meters)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
Meters	°		°		°		°		°		°		°		°		°		°	
Surface	S 35 E	0.6	S 60 E	1.4	S 82 E	0.7	S 87 E	0.8	S 18 W	0.3	S 13 W	0.5	S 73 W	0.9	S 83 W	0.4	S 31 E	1.5	S 89 W	0.7
500	S	0.4	S 20 W	4.2	S 31 E	5.1	S 54 E	2.2	S 53 W	1.7			N 36 W	2.9	S 77 W	3.6	S 11 W	1.6	S 63 W	4.2
1,000	N 40 W	1.0	S 37 W	5.7	S 10 E	5.1	S 35 W	1.3	S 85 W	4.0			N 17 W	5.8	N 84 W	5.3	S 27 W	1.7	S 84 W	5.5
1,500	N 8 W	0.4	S 51 W	4.2	S 13 E	5.2	N 55 W	2.4	N 85 W	4.8	S 33 W	0.6	N 21 W	5.7	N 72 W	6.8	S 45 W	2.8	S 83 W	8.8
2,000	N 79 W	0.7	S 54 W	3.3	S 5 W	5.3	N 64 W	3.6	N 83 W	6.2	S 2 E	1.4	N 26 W	6.6	N 81 W	8.3	S 44 W	4.3	N 84 W	9.6
2,500	N 82 W	2.5	S 59 W	3.3	S 8 W	4.2	N 56 W	4.7	S 88 W	7.6	S 61 W	1.2	N 35 W	7.6	N 68 W	7.6	S 32 W	5.8	N 83 W	10.1
3,000	N 86 W	3.1	S 46 W	3.7	S 21 W	4.0	N 78 W	5.6	N 89 W	9.6	S 69 W	2.6	N 39 W	8.2	N 55 W	7.0			N 89 W	10.1
4,000	N 48 W	8.8			S 56 W	3.5	S 84 W	6.4	S 72 W	5.4	S 75 W	5.2	N 49 W	9.6	N 58 W	11.7				
5,000					S 70 W	5.1	N 82 W	7.8	N 87 W	8.4	N 58 W	5.2	N 45 W	11.8	N 64 W	11.4				

TABLE 3.—*Observations by means of kites, captive and limited-height sounding balloons, and airplanes, during May, 1929*

	Broken Arrow, Okla.	Due West, S. C.	Ellendale, N. Dak.	Groesbeck, Tex.	Royal Center, Ind.	Naval air station D. C.
Mean altitudes (meters) m. s. l., reached during month	2,534	2,034	2,412	2,692	2,633	2,984
Maximum altitude (meters), m. s. l., reached and date	[1] 4,399	[2] 3,754	[3] 4,374	[3] 5,306	[4] 5,103	[1] 3,852
Number of flights made	27	24	32	27	22	12
Number of days on which flights were made	27	23	30	27	22	12

[1] 28th. [2] 4th. [3] 5th. [4] 27th.

In addition to the above there are approximately 100 pilot balloon observations made daily at some 45 Weather Bureau stations in the United States.

WEATHER IN THE UNITED STATES

THE WEATHER ELEMENTS

By P. C. DAY

GENERAL CONDITIONS

May, 1929, was notable chiefly on account of the persistence of low temperatures, though at no time did frost seriously threaten the staple crops. The continued cold, however, augmented by frequent rains and wet soil, delayed to some extent the advance of the season which was late over wide areas of the interior and southern parts of the country.

PRESSURE AND WINDS

The month opened with cyclonic centers located over lower Michigan and central Texas, and extensive areas of precipitation associated with thunderstorms had prevailed during the preceding 24 hours from the Great Lakes westward to the northern Rocky Mountains and from Arkansas and Missouri eastward to the Atlantic coast, some snow occurring in the more northern districts. By the morning of the 2d the Michigan center had largely disappeared, but the Texas one had developed materially and was central over the lower Ohio Valley as a severe storm attended by local high winds, tornadoes, hail and other storms, heavy rains, local snows, and material damage to property of various kinds. Nearly 40 persons were killed and many injured by tornadoes which occurred in scattered areas from Arkansas and Missouri eastward to near the Atlantic coast. Nine persons were killed by a tornado at Wheatley, Ark., on the afternoon of the 1st, and 13 at Rye Cove, Va., on the 2d, and 15 or more additional deaths occurred at other scattered points in Maryland, Virginia and elsewhere in the storm area. The total losses from these storms are estimated as amounting to more than $3,000,000. This cyclone moved northeastward to the St. Lawrence Valley during the following day, increasing somewhat in intensity over the Atlantic coast districts without, however, the severe local storms that marked the two preceding days, but with heavy rains continuing in many eastern sections and snow occurring locally at many places in the northern portions of the storm area. By the morning of the 4th the storm had moved northwestward to the vicinity of Hudson Bay with decreasing intensity.

At the morning observation of the 6th low pressure had overspread the southern Plains and scattered rainfall, generally light, had occurred over a narrow area from the middle Rocky Mountains eastward and southeastward to Florida and the middle Atlantic coast and thence to New England and eastern Canada. By the following morning the rain area had become general over most eastern districts, the falls becoming rather heavy at points in the Ohio Valley and Southeastern States, but in most other parts of the country clear weather prevailed, continuing till about the end of the first decade, except for local rains in portions of the Gulf States.

The first half of the second decade had rather rainy conditions that gradually overspread the central valleys, beginning about the 11th and slowly extending eastward during the following several days reaching the Atlantic coast by the 15th, at which time another low-pressure area had advanced to the western Lake region; by the morning of the 16th this low-pressure area was central near northern New England and precipitation had occurred over considerable areas from the Mississippi Valley eastward over the Lake region and Ohio Valley and locally in parts of the Gulf States and New England.

At the morning observation of the 18th cyclonic conditions existed in the Southern Plains and west Gulf regions with local heavy rains occurring. By the following morning rain had overspread most districts to the eastward and heavy rains had occurred at many additional points in the Gulf States and had extended into the Ohio Valley and East Gulf States. At the end of the second decade the rain area was confined to a rather narrow strip along nearly the entire Atlantic coast from Florida to Maine, continuing during the following day over the same districts save for northern New England.

The early part of the third decade was mostly without rain except along the Atlantic coast, as stated above, and for a few local showers elsewhere, until about the 26th, when rainy conditions set in over the Rocky Mountain region and portions of the South from Texas eastward to and including portions of the lower Ohio Valley. During the following day the rain area extended to other parts of the West and eastward over the northern Plains to the upper Lakes and continued in portions of the South, heavy rains being reported from portions of Alabama and Georgia.

Scattered rains fell during the last few days of the month in many interior and some southern districts, but no general cyclone crossed any large part of the country.

Over the far western districts the month was mainly without important cyclonic formation as is usually the case in May, and there was little rain or other atmospheric disturbance.

The average sea-level pressure for the month was above normal in all parts of the United States, save over a small area in central and southern California, and it was also above normal in Canada as far as observations disclose. The change in pressure from the preceding month was likewise positive in all parts of the country save for the portions of California noted above and like conditions existed in Canada also.

The important winds of the month were mainly of the local character common to the warm season and occurred mainly on the first and second days and also during various parts of the second and third decades, a few occurring on most days of each and widely scattered in location.

The details of the more important storms of the month appear in the special table at the end of this section.

TEMPERATURE

May, on the whole, was a cold month, though there were few cases of sudden and sharp changes to lower temperatures, the most notable important cases of decided falls in temperature being on the 2d and 3d, when changes from 20° to 30° cooler occurred following the passage of an area of low pressure. This moved across the central valleys and eastern districts with corresponding high temperatures and was followed by an anticyclone of considerable strength, so temperature dropped to near or below the freezing point in some interior and western portions. Marked falls occurred again on the 15th to 17th when high pressure over-

spread the northern and central districts from the Rocky Mountains eastward, bringing temperatures within a few degrees of freezing at many points near the northern border.

The following resumé by weekly periods shows the main features of the temperature conditions during the several portions of the month. The first week was abnormally cold, particularly in the interior valleys and Northwest where the weekly averages ranged from 6° to 12° below normal, and hard freezes occurred in some North-Central States. In other sections, however, the weekly averages were not so low and in portions of the Atlantic Coast States and in the South and far West they were somewhat above normal. During the week ended May 14, the weather continued colder than normal over most districts from the Rocky Mountains eastward, though the negative departures were not large; districts near the Gulf, however, had slightly more than normal warmth and the week was mainly warmer than normal in the Plateau and Pacific Coast States. Some freezing temperatures were reported this week along the northern border and in the elevated areas of the West. The week ended the 21st continued cooler than normal over most central and eastern districts save along the immediate Atlantic coast, and it continued warmer than normal as in the preceding week over most far Western States; the week, as a whole, showing slightly greater negative departures from the normal than that preceding. The week ended the 28th continued cooler than normal over the eastern portions during the earlier part, but later in the week there was a reaction to warmer in the Northwest and the latter part had temperatures above normal in most eastern districts, the averages for the week being materially above normal from the Great Lakes and upper Mississippi Valley westward, and as a whole, continued warmer than normal over most of the far West. The week, as a whole, was cooler than normal in the East and South although temperatures were becoming rather high as the week closed over eastern districts. The last three days were unseasonably warm over the eastern half of the country, but about normal temperatures prevailed in other districts.

The month, as a whole, was distinctly cool over all parts of the country, save for small areas along or near the Atlantic coast and over the Plateau and Pacific Coast States, where the monthly averages were somewhat above normal. In portions of the Missouri, Mississippi, and Ohio Valleys, and the Lake region the negative departures ranged from 2° to 5° per day.

The maximum temperatures were above 90° at some time during the month in all the States, and above 100° at points in most of the Southwestern States, the highest for the month, 110°, occurring in southeastern California. The extreme heat was registered mainly during the last few days.

The lowest temperatures were recorded early in the month as a rule, and they were below freezing for short periods in most States except those of the Southeast. The lowest reported, 5° below zero, occurred at an exposed point in Wyoming, though temperatures only a few degrees higher occurred at a number of other points in the high western mountains.

PRECIPITATION

May was a wet month over most districts from New Mexico northeastward to the middle Great Lakes and thence eastward to the Atlantic coast. Within this area the monthly precipitation was nearly everywhere above the normal falls of May and over some areas the amounts were the greatest of record for that month, notably in central and southwestern Missouri and near-by areas of eastern Kansas and western Arkansas, in central and southern Texas, and at points in New Mexico. At St. Louis, Mo., the total fall for May was the greatest in nearly 60 years of official Government records and similar conditions obtained at points in Texas, Galveston reporting the greatest May amount in over half a century, with the maximum fall of record for short periods, 5.18 inches in two hours, 3.32 inches in one hour, and 2.18 inches in 30 minutes, all on the 18th. On the other hand, there was a marked deficiency in precipitation at points in Iowa, Dubuque reporting the least monthly amount for May in 55 years of observations at that place, and precipitation was generally less than normal for May from the Lake region westward and southwestward to the Pacific coast.

The rainfall, where less than normal, was so distributed, however, that no large area was without some precipitation for unduly long periods and moisture was, in the main, sufficient for the needs of crop growth.

SNOWFALL

The falls of snow usual for May occurred in the western mountain regions though there appears to have been but little in the mountains of California. However, some large amounts were measured in the high elevations of the central Rocky Mountains, with a maximum total of 59 inches in Colorado and considerable but smaller amounts in the nearby mountains of New Mexico and Wyoming, and lesser falls in Montana, with scattered falls in the mountains of the Plateau region.

Over districts from the Rocky Mountains eastward snow was light along the northern border, but further south in a small area from central Missouri northeast to Michigan an unusual fall of snow occurred on the night of May 1–2, continuing into the 3d in northern Michigan. In this area depths ranging up to 5 or even 10 inches occurred, and at many points in the area of snowfall it was the latest occurrence of record as well as the heaviest fall ever reported in May.

RELATIVE HUMIDITY

From the middle and southern Rocky Mountains eastward the percentages of relative humidity were nearly everywhere above normal, but to the northward, also to westward of the Continental Divide humidity percentages were generally less than normal, and in many sections the negative departures were large. At Yuma, Ariz., the average of the afternoon readings was only 11 per cent, the lowest of record for May. In some of the southern sections, notably from New Mexico eastward, the percentages were markedly high, ranging up to 10 or even 15 per cent above the normal.

SEVERE LOCAL STORMS, MAY, 1929

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path, yards [1]	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Perry County, Mo.	1	2 p. m.	3-6 mi.		$100,000	Hail, wind and rain.	2 barns and 1 dwelling unroofed; many windows broken; crops and autos damaged; several persons and some livestock injured; path 20 miles.	Official, U. S. Weather Bureau.
Tucker, Okla., to Fort Smith, Ark.	1	2:15-2:37 p. m.	60		54,000	Tornado	Damage chiefly to buildings; 13 person injured	Do.
Jethro, Ark.	1	2:25 p. m.	600		50,000	do	Character of damage ot reported; path 12 miles	Do.
Cora to Raleigh, Ill.	1	3 p. m.	2-6 mi.		720,000	Hail, rain and wind.	Roofs pierced; windows broken; greenhouses practically demolished; fruit ruined; path 6 miles long.	Do.
Frankston, Tex.	1	3 p. m.	300		2,500	Tornado	Buildings damaged	Do.
Rex, Ark.	1	3:30 p. m.	400		40,000	do	Village practically wiped out; 6 persons injured; path 5 miles.	Do.
Dallas, Tex.	1	4 p. m.				Wind	Buildings considerably damaged	Do.
Wheatley, Ark.	1	6:45 p. m.	200	9	250,000	Tornado	Numerous structures blown down or damaged; telephone communication cut-off; 20 persons injured.	Do.
Newport, Tenn. (10 miles south of).	1	P. m.				Heavy hail	Much damage to roofs, orchards and gardens	Do.
Seligman, Mo.	1	P. m.	15 mi.		15,000	do	Vegetation beaten and roofs damaged over an area 15 miles square.	Do.
Hamilton (northern) and adjacent Counties, Ohio.	1-2					Wind, hail, and thunderstorm.	Considerable damage to trees and greenhouses; truck crops injured.	Do.
Rye Cove, Va.	2	2 p. m.		13	100,000	Tornado	A school building and several homes wrecked. other houses unroofed: trees uprooted; about 50 persons injured.	Do.
Woodville, Va.	2	3:30 p. m.		1	200,000	do	2 churches, a school building, and 4 homes demolished; others damaged; about 20 persons injured.	Do.
Jacksonville Heights, Fla., and vicinity.	2	4:20 p. m.	100	1	25,000	Tornadic wind	Several cottages demolished; trees and roofs damaged; 8 persons injured; path, 2 miles.	Do.
Morgantown, W. Va., to Uniontown, Pa.	2	4:20 p. m.				Probably tornado	A number of houses wrecked or damaged; several persons injured: trees prostrated.	Do.
Bath County, Va.	2	6 p. m.	250-800		75,000	Tornado	Much destruction of farm property; over head wires blown down; poultry killed; many persons injured; path 17 miles.	Do.
Hamilton, Va., to Taneytown, Md.	2	7:30-10 p. m.	100-130	2	150,000	do	Farm property damaged or destroyed; poles broken; trees uprooted; several persons injured.	Do.
Lagrange to Catlett, Va.	2	8 p. m.		4	50.000	do	Several homes and farm buildings demolished; others damaged; livestock killed; autos wrecked.	Do.
Montgomery and Howard Counties, Md.	2	9 p. m.	150-250	4	80,000	do	Buildings partially or entirely destroyed on 6 farms.	Do.
Cocke to Washington Counties, Tenn.	2			2		do	Large trees twisted; a score of homes damaged or demolished; 4 persons injured at Cherokee.	Do.
Franklin County, Ohio.	2	P. m.		2	25,000	Tornadic wind	City workhouse at Columbus demolished; other minor damage; 6 persons injured.	Do.
South Carolina.	2				900,000	Wind	Much sprout cotton and corn seriously injured, necessitating replanting.	Do.
Washington, D. C.	2	P. m.				do	Some property damage; 62 trees uprooted or broken off.	Do.
Illinois, Indiana, and Michigan.	2-3				775,000	Snow and wind	Overhead wires down; highways obstructed; much damage to orchards.	Do
South Allapattah, Fla.	5	2:30 p. m.	2,640		30,000	Hail	Damage chiefly to crops	Do.
Berlin, N. H.	5	4 p. m.			300,000	Tornado	A number of buildings wrecked, others damaged.	Boston Herald, Mass.
Bolivar and Coahoma Counties, Miss.	7					Wind and hail	Crops injured; property damaged	Official, U. S. Weather Bureau.
Fairfax, Okla.	7	11 p. m.				Heavy hail	Fruit, crops, and other property damaged	Do.
Peach County, Ga.	8					Severe hail	Great damage to peach crop	Do.
Alexandria, La.	9		3,520		5,000	do	Considerable damage to roofs over area 2 miles square.	Do.
Johnson, Kans. (20 miles northeast of).	10	6 p. m.	200		900	Small tornado	Minor damage to farm buildings over path 1 mile long.	Do.
Alexander, Kans. (near)	10	P. m.				do	Minor damage reported	Do.
Otis, Kans. (near)	10	do				do	do	Do.
Chanute, Kans. (near)	11	5 p. m.	33		1,500	do	Farm buildings damaged; a barn completely demolished; 1 person injured.	Do.
Huntsdale to Bethel, Mo.	11	6 p. m.	880		12,000	Heavy hail	Crops, roofs, and windows damaged over path 4 miles long.	Do.
Fort Wayne, Ind., and vicinity.	11				15,500	Wind and electrical.	Power and light service impaired; tower damaged by lightning.	Do.
Pancoastburg (near) to Five Points (near), Ohio.	14	4 p. m.			3,000	Tornado	Small damage to trees and property	Do.
Radnor (near), Ohio.	14	7 p. m.			4,100	do	Character of damage not reported	Do.
Wooster (near), Ohio.	14	9 p. m.				Probably tornado	A home unroofed; trees uprooted	Do.
Claremore, Okla. (6 miles northeast of).	15	P. m.				Tornado	Minor property damage	Do
Marinette, Wis.	15	do			30,000	Severe squall	Considerable damage to church steeples, farm buildings, and silos.	Do.
Tiskilwa to Hollowayville, Ill.	15		160		6,000	Probably tornado	Trees blown down and a few barns wrecked over path 15 miles long; 2 persons injured.	Do.
Portland, Me.	16	1:40 p. m.			25,000	Tornado	Several buildings wrecked, others damaged	Do.
Kezar Falls and South Hiram, Me.	16	P. m.			2,000	Wind	Numerous buildings wrecked or unroofed; trees twisted; timber damaged.	Do.
Catron County, N. Mex.	16		220-880			Tornado	A house, fences, and forest trees damaged	Do.
McCamey, Tex.	17	11:15 a. m.	100		2,000	do	Buildings damaged	Do.
Electra, Tex.	17	2 p. m.	15 mi.		175,000	Wind	Extensive damage to crops and buildings; 1 person injured.	Do.
Dundee, Tex.	17	2:30 p. m.	440		20,000	Tornado	Damage chiefly to buildings; 3 persons injured	Do.
Clara, Tex., and vicinity.	17	4 p. m.	880			Wind	Oil derricks and buildings badly damaged; 1 person injured.	Do.
Del Rio, Tex. (near)	17	4:30 p. m.	3,500		6,500	Hail	Crops injured	Do.
Byers, Tex.	17	do	880		10,000	Wind	Buildings damaged	Do.
Waco, Tex. (near)	17	5:30 p. m.	880		8,000	do	Crops and buildings damaged	Do.
Springfield, Mo.	18	8:55 a. m.	33		1,200	Small tornado	Minor damage to buildings; path three-fourths mile long.	Do.
Westfield, Tex.	18	12:30 p. m.	20		5,000	Tornado	Buildings damaged; poultry killed; 4 persons injured.	Do.
Charles County, Md. (southeastern).	19					Thunder gust	Barns unroofed; windows broken; trees uprooted.	Do.

[1] "Mi." signifies miles instead of yards.

Severe local storms, May 1929—Continued

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
New Jersey (central and northern).	19					Wind	Power and communication lines and houses damaged.	Official, U. S. Weather Bureau.
Ysleta, Tex	20	P. m.				Hail	Much cotton destroyed or damaged	Do.
Moriarty, N. Mex	21					Tornado and hail	Minor property damage	Do.
Fabens, Tex	22	5 p. m.	1,760			Hail	Some cotton and considerable fruit destroyed	Do.
Del Rio, Tex. (near)	23					Tornado	Severe damage to crops	Do.
Smithville, Okla	25	4 p. m.	33		700	Wind	Every business house except one damaged	Do.
Cuthbert, Tex. (near)	25		3 mi.		250,000	Heavy hail	Damage principally to crops and buildings; poultry and livestock killed.	Do.
Sealy, Tex	26	12:15 a. m.	500		12,500	Tornado	Several homes and 2 churches demolished	Do.
Beaumont, Tex	26	3 a. m.		1	25,000	Wind	Oil derricks wrecked; plate glass broken	Do.
Pasadena, Tex	26	do.	20		2,000	Tornado	Crops and buildings damaged	Do.
Hyannis, Nebr. (near)	26	5 p. m.	16		250	do.	Slight damage to buildings on one ranch	Do.
Encinal, Tex. (near)	26	8:20 p. m.	880			Hail	Young cotton killed	Do.
Albert Lea, Minn. (near)	26				10,000	Tornado	Considerable property loss	Do.
Lyon County, Iowa	28	5 p. m.			2,700	do.	Character of damage not reported	Do.
Plymouth, Clay, and Palo Alto Counties, Iowa.	28	do.			3,500	Wind	do.	Do.
Yoakum, Tex	28	11 p. m.	400		700	Tornado	2 buildings damaged	Do.
Johnstown Pa	28			2		Thunderstorm	Grandstand struck by lightning; 6 persons injured.	Do.
Columbus, N. Mex	30					Tornadic wind	Wire service impaired; several buildings wrecked.	The New Mexican (Santa Fe, N. Mex.)
Florence, N. J	31					Thunderstorm and wind.	Buildings damaged; wires broken by falling trees.	Official, U. S. Weather Bureau.

RIVERS AND FLOODS

By H. C. FRANKENFIELD

The Mississippi River was above the flood stage from the mouth of the Ohio River southward at the end of May, and probably will not fall below that stage at New Orleans, La., until the end of June. Discussion of this flood will therefore be included in the report for June.

The outstanding floods of the month of May were those of the rivers of central and eastern Texas. They were caused by rains attendant upon a series of slow moving and often poorly defined barometric depressions from the Southern Plateau and the extreme Southwest during the last two decades of May. After a month of generally dry weather, these depressions brought light rains as early as May 10 and heavy general rains on May 12–13, and still heavier ones on May 17–18, 25–26, and especially May 28–30. As a whole the month was the wettest of record for the State of Texas, with an average rainfall of 7.70 inches against the previous high record of 7.68 inches in May, 1914. The greatest fall of the month, 22.55 inches, occurred at Rockland on the Neches River, with a maximum fall, as recorded by the observer, of 11.05 inches between 4 p. m. and midnight, May 27.

Resulting floods were, of course, severe and the heavy downstream rains, coming as they did when the middle and upper portions of the rivers were at or above the flood stages, intensified the high stages as the crests advanced.

The floods were greatest and most destructive in the Trinity and Brazos Rivers and their tributaries. The Sabine River flood was moderate, while those in the Colorado and Guadalupe Rivers were quite pronounced The Neches flood was also moderate.

The most spectacular floods of the State were those of the Buffalo River and White Oak Bayou above and through Houston on May 31. They were due to the heavy rains of May 28–30, and the stages reached were said to have been the highest since 1879, although there are no actual gage readings to substantiate this statement. Levels run by the city engineer of Houston, Mr. Fugate, showed a stage on May 31 of about 32 feet above mean tide immediately below the confluence of the two streams which is usually at tide level. Mr. Fugate also computed previous high stages as follows: 1854, 32.3 feet; 1879, 34.3 feet; 1907, 24.9 feet.

A considerable area of the city of Houston was flooded, and damage and loss amounted to about $1,000,000.

Timely warnings were issued for all floods, and the aggregate savings of livestock and other movable property reached a very gratifying figure. Unfortunately the growing season was so well advanced that the greatest losses will come from crop destruction. How much relief may be obtained from later plantings is problematical, but in any event the actual losses will run into millions of dollars.

Loss and damage as reported were as follows. The figures given are very incomplete:

Drainage	Tangible property	Crops			Livestock and other movable property	Suspension of business	Total	Saved through warnings
		Mature, amount	Prospective					
			Acres	Amount				
Sabine	$50,000	$15,000	1,700	$26,000			$91,000	
Neches	25,000	25,000	2,500		$15,000		65,000	
Trinity	254,250		29,970	2,239,000	2,500	$63,500	2,559,250	$187,500
Brazos	88,000	438,000	173,950	1,779,625	11,500	28,000	2,345,125	616,000
Total	417,250	478,000	208,120	4,044,625	29,000	91,500	[1] 5,000,375	803,500

[1] Plus $1,026,175 not itemized.

Later report will be made regarding loss and damage figures for the floods in the Colorado, Guadalupe, and Nueces Rivers.

There were no floods of consequence in the Atlantic and East Gulf drainage areas, although high stages prevailed throughout the month in the Santee River, which river has been in flood almost continuously since February 10.

Little or no damage resulted from these floods, except in the lowest bottom lands along the Black Warrior River below Tuscaloosa, Ala., and the Tombigbee River below Demopolis, Ala. In this district the reported loss of property amounted to $129,300, of which $23,900 was in tangible property, $14,000 in prospective crops (12,400 acres), $14,000 in livestock and other movable property,

and $45,500 through suspension of business. The given value of property saved through the warnings was $183,100.

No flood stages occurred in the Ohio River above Dam No. 47, Newburgh, Ind. At and below this place flood stages were general although not of great consequence, despite the rather high stages between Shawneetown, Ill., and Dam No. 50, Fords Ferry, Ky., and from Dam No. 53, Grand Chain, Ill., to the mouth of the river. At Cairo, Ill., the river was continuously above the flood stage of 45 feet from March 6 to April 21, and again from April 29 to June 2, all inclusive.

Reports of loss and damage in the Cairo district are yet to come. Elsewhere along the Ohio River, while there was some inconvenience and delay in farming operations, there was no material damage. Moderate floods in the interior rivers of the State of Ohio also passed off without damage of consequence.

Floods in the lower Wabash system of Indiana were more damaging. They were caused by four rain periods, and occurred in two or three irregular groups. As the growing season was quite well advanced and Wabash flood crests were generally higher than in April, the damage to prospective crops was comparatively large, the total estimate amounting to $319,300. There were also $4,680 in tangible property losses and $53,200 due to business suspension, a total of $377,360. The reported value of property saved through the warnings was $44,250.

At the beginning of the month the Mississippi River about the mouth of the Ohio was generally in flood as far north as the mouth of the Des Moines River, and it was not until May 28 that the river fell below the flood stage at Cape Girardeau, Mo., the first station above Cairo. Stages had also been much above normal during most of April and May, and the prolonged high waters ruined wheat and prevented planting in unleveed ground. Levees below St. Louis were softened, and the Grand Tower, Ill., levee broke, flooding 2,620 acres. There was also much crop loss under unbroken levees on account of inside flooding from frequent and heavy rains. City losses were mostly in cessation of business activities.

In the 230 miles of the alluvial drainage of the Illinois River below Utica, Ill., stages have been high since December, 1928, with three well defined swells, one in the latter part of January and the first half of February, a second in the latter part of March, and a third in the first half of April, 1929. They were not unusually high, but with their long duration they were high enough to greatly interfere with the natural drainage into the river.

The Grand River of Missouri was in severe flood from April 20 to 27, and most of the bottom-land wheat left by the March flood was killed, yet the Grand Valley suffered less than most other parts of the State of Missouri during April and May. (However, an unusually high flood came in June, and all farming operations for May came to naught.)

There was a severe flood in the Osage River of Missouri during the second week of April and a very high one in the second week of May. Wheat in bottom lands was an entire loss, highways and fences were greatly damaged, and in the town of Tuscumbia everything was at a standstill during the May flood. The business section of the town was entirely under water, but the timely warnings gave ample time to remove merchandise and there was no actual loss.

There was one flood in April and three in May in the Meramec River of Missouri, but only minor damage resulted. Similar conditions prevailed along the Black River of Missouri.

During April and May there were frequent fluctuations in the Missouri River below the mouth of the Osage. Above the mouth of the Osage as far as Lexington the river was high, but there was only one flood, and that during the latter part of April. Damage was of the same nature as in other portions of the district plus a heavy loss entailed through the enforced suspension of work in connection with the construction of the new highway bridge at Hermann, Mo.

Loss and damage data in the St. Louis district so far as reported are as follows:

River	Tangible property	Crops		Live-stock and other movable property	Suspension of business	Total
		Matured	Prospective			
Grand	$65,000	$125,000	$75,000			$265,000
Osage	35,000	75,000	25,000			135,000
Meramec	5,000	7,000	5,000			17,000
Black	1,000	1,500	1,000			3,500
Missouri [1]	172,000	115,000	313,000	$5,000	$56,000	661,000
Illinois	10,000	13,000	590,000		10,000	623,000
Mississippi [2]	239,000	165,000	590,000	82,000	360,000	1,436,000
Total	527,000	501,500	1,599,000	87,000	426,000	3,140,000

[1] Below Lexington, Mo.
[2] Not including towns of Louisiana and Cape Girardeau, Mo.

The reported value of property saved through the warnings was $475,000.

During May there were floods in the basins of the Smoky Hill, Neosho, Marais des Cygnes (Osage), and Marmaton Rivers of Kansas. The Smoky Hill flood was worst at Salina, Kans., where property damage was estimated at $50,000. During the night of May 10-11, 5.85 inches of rain fell at Herington, Kans., and Lyons Creek, a nearby tributary of the Smoky Hill River, rose 10 feet in 20 minutes, sending a raging torrent through the city. Three men were drowned, the Main Street bridge was washed out, and six bents of a railroad bridge were lost. Other damage was of the usual nature and the total was estimated at $200,000. The total reported damage in the Smoky Hill Basin was $536,000. In the Neosho Basin several towns were more or less overflowed and crops in Neosho and Labette Counties badly damaged. At Council Grove, Kans., 4.60 inches of rain fell during the night of May 10–11, and water stood 2 to 3 feet in depth on Main Street. Local damage was estimated at $50,000. The total reported for the Neosho Basin within the State of Kansas was $391,850, mostly in growing crops.

The Marais des Cygnes (Osage) flood was not very serious, although one life was lost and damage amounted to $50,000.

Another severe flood occurred in the Marmaton River, a tributary of the Osage, during May 11 and 12, and at Fort Scott, Kans., the crest stage at 7:20 a. m., May 12, was 37.1 feet, only 0.2 foot below that of August, 1927. Loss and damage amounted to about $50,000. The reported value of property saved through flood warnings in this eastern Kansas district, excluding direct Arkansas River drainage, was $71,000.

There were moderate floods in the Arkansas River within the State of Kansas, but without results of consequence. They were caused mainly by the heavy rains of May 10–11 at Great Bend, Kans., and over the drainage basin of Walnut Creek in which the resultant damage was estimated at $60,500, of which $31,000 was in tangible property, $28,500 in prospective crops, and $1,000 in livestock and other movable property.

Below the Kansas-Arkansas line the Arkansas and Neosho Rivers were generally in flood, as was also the Verdigris River of Kansas and Oklahoma, and the White River of Arkansas. The floods were caused by the same series of heavy rains that fell over eastern Kansas with the same maximum effectiveness on May 11 and 12. The Arkansas River was not in actual flood above Webbers Falls, Okla., but at and below that place flood conditions were quite marked. There were three decided rises from Webbers Falls to Fort Smith, Ark., with crests during the second rise from 6 to 8 feet above the flood stage on May 15 and 16. However, by the time Little Rock, Ark., was reached, this second crest was the only one of importance remaining, and this condition continued to the mouth of the river. Crest stages were relatively lower east of Fort Smith, except near the mouth of the river where backwater from the Mississippi flood caused very high stages that continued at the close of the month.

The floods in the Verdigris and lower Neosho Rivers were heavy and destructive and about 125,000 acres of land overflowed, 15,000 of which were in the Verdigris district of Kansas. East of Fort Smith the overflowed area in the Arkansas basin was estimated at 500 square miles, or 320,000 acres, much of which consisted of cultivated land. The area of overflowed land in the White River Basin was about 800 square miles, or 512,000 acres, notwithstanding the fact that the maximum stages were only a few feet above the flood line.

Reports of loss and damage were very incomplete. Figures received show at least $1,750,000, mainly in prospective crops, with the exception of about $250,000 due to suspension of sand and gravel business in Oklahoma. In the Fort Smith district savings to the same industry through warnings were given as $100,000.

Floods in Red River west of Shreveport, La., and in the Sulphur River of Texas were of good proportions and quite damaging to highways and growing crops. Loss and damage as reported aggregated $89,450, the Sulphur River share being $17,000. Of the total amount, $78,450 was in prospective crops (13,189 acres), and $11,000 in tangible property. Reported value of property saved through flood warnings, $73,700. One life was lost.

Moderate floods in the Colorado River and tributaries and in the Rio Grande in New Mexico were well covered by warnings. No material damage appears to have been caused.

[All dates in May unless otherwise specified]

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
ATLANTIC DRAINAGE	*Feet*			*Feet*	
Connecticut: Hartford, Conn	16	(1)	9	17.7	1.
Chenango: Sherburne, N. Y	8	3	3	8.3	3.
Neuse: Smithfield, N. C	14	23	23	14.0	23.
Cape Fear: Elizabethtown, N. C	22	23	23	23.0	23.
Peedee: Mars Bluff, S. C	17	4	5	17.1	4 and 5.
		9	12	17.4	10 and 11.
		23	26	18.0	25.
Lynches: Effingham, S. C	14	8	10	14.8	9.
Santee:					
Rimini, S. C	12	(1)	(2)	17.7	6.
Ferguson, S. C	12	(1)	(2)	17.5	Mar. 10.
Jamestown, S. C	12	----------	(2)	17.4	11–13.
Congaree: Columbia, S. C	15	2	3	17.2	2.
Saluda:					
Pelzer, S. C	7	7	7	7.6	7.
Chappells, S. C	14	(1)	4	19.5	2.
Three Mile Post, N. C	8	2	3	9.8	3.
Broad: Carlton, Ga	11	2	2	14.0	2.
Oconee: Milledgeville, Ga	22	2	2	22.8	2.
Ocmulgee: Abbeville, Ga	11	10	11	11.2	10, 11.
EAST GULF DRAINAGE					
Alabama: Selma, Ala	35	10	10	35.1	10.
Coosa:					
Gadsden, Ala	22	4	5	23.0	4–5.
Lock No. 4, Lincoln, Ala	17	2	7	17.9	5.
Cahaba: Centerville, Ala	25	19	19	25.0	19.
Tombigbee: Lock No. 4, Demopolis, Ala	39	22	24	40.3	23.
Black Warrior: Lock No. 10, Tuscaloosa, Ala	46	9	11	48.5	10.
Pearl: Jackson, Miss	20	(1)	1	20.6	Apr. 29–30.
GREAT LAKES DRAINAGE					
St. Joseph: Montpelier, Ohio	10	3	5	11.2	3.
Saginaw: Saginaw, Mich	19	5	6	19.0	5–6.
Flint: Flint, Mich	11	4	4	11.2	4.
MISSISSIPPI DRAINAGE					
Ohio:					
Dam No. 47, Newburgh, Ind	35	8	19	38.0	17.
Evansville, Ind	35	8	19	38.5	17.
Dam No. 48, Cypress, Ind	35	10	19	37.4	16–17.
Shawneetown, Ill	35	8	June 1.	40.2	18.
Dam No. 50, Fords Ferry, Ky	35	8	June 1.	41.0	17–19.
Dam No. 51, Golconda, Ill	38	13	21	39.1	15, 16.
Paducah, Ky	43	13	19	43.9	16.
Dam No. 52, Brookport, Ill	43	13	21	44.2	16.
Dam No. 53, Grand Chain, Ill	44	6	June 1.	49.3	18.
Cairo, Ill	45	(1)	June 2.	52.7	19.
Shenango: Sharon, Pa	9	3	5	10.9	4.
Tuscarawas: Coshocton, Ohio	8	6	6	8.4	6.
Walhonding: Walhonding, Ohio	8	15	15	8.5	15.
Scioto:					
Larue, Ohio	11	15	15	12.2	15.
Circleville, Ohio	10	----------	16	11.7	16.
Green:					
Lock No. 4, Woodbury, Ky	33	8	11	36.6	9.
Lock No. 2, Rumsey, Ky	34	9	15	36.0	12–13.
Big Barren: Bowling Green, Ky	20	8	8	21.1	8.
Wabash:					
Lafayette, Ind	13	4	4	13.3	4.
		15	21	16.7	16.
		5	6	16.7	5.
Covington, Ind	16	15	22	20.0	16–17.
		30	30	16.0	30.
Terre Haute, Ind	16	14	23	19.4	20.
Vincennes, Ind	14	16	28	20.1	22.
Mt. Carmel, Ill	16	6	12	18.7	10.
		14	31	23.7	23.
White: Decker, Ind	18	17	28	22.0	25.
White, East Fork:					
Seymour, Ind	10	15	15	10.3	15.
		20	21	10.4	20.
Shoals, Ind	20	19	23	21.5	20.
Elliston, Ind	19	15	24	24.9	22.
		30	31	19.1	30.
White, West Fork: Edwardsport, Ind	15	6	8	16.9	7.
		15	26	18.9	23.
		30	(2)	16.8	31.
Tennessee: Riverton, Ala	33	9	14	36.0	11.
Big Pigeon: Newport, Tenn	6	7	7	7.4	7.
Clinch: Clinton, Tenn	25	21	22	28.3	21.
Elk: Fayetteville, Tenn	14	7	7	14.2	7.
		9	10	18.5	9.
Mississippi:					
Keokuk, Iowa	14	(1)	3	19.4	Mar. 23.
Warsaw, Ill	17	(1)	3	22.0	Mar. 23.
Quincy, Ill	14	(1)	8	21.4	Apr. 23, 27.
Hannibal, Mo	13	(1)	11	22.1	Apr. 27.
Louisiana, Mo	12	(1)	11	21.1	Apr. 27.
		13	21	13.1	May 15.
Grafton, Ill	18	(1)	23	20.2	Apr. 28.
Alton, Ill	21	(1)	24	30.1	Apr. 28.
St. Louis, Mo	30	(1)	7	34.6	Apr. 27–28.
		15	23	33.3	20.
Mississippi:					
Chester, Ill	27	(1)	25	33.3	Apr. 28.
				32.6	May 22.
Cape Girardeau, Mo	30	(1)	28	37.4	22.
New Madrid, Mo	34	(1)	(2)	41.3	19, 20, 23, 24.
Memphis, Tenn	35	(1)	(2)	41.7	26.
Helena, Ark	44	(1)	(2)	52.6	28–30.
Arkansas City, Ark	48	(1)	(2)	58.8	29–31.
Greenville, Miss	42	(1)	(2)	53.2	29–June 1.
Vicksburg, Miss	45	(1)	(2)	55.2	June 6, 7.
Natchez, Miss	46	(1)	(2)	54.5	June 5–11.
Angola, La	45	(1)	(2)	----------	
Baton Rouge, La	35	(1)	(2)	43.5	June 10–12.
Donaldsonville, La	28	(1)	(2)	34.0	June 10.
Reserve, La	22	(1)	(2)	----------	
New Orleans, La	17	(1)	(2)	20.0	June 9.
Salt: New London, Mo	20	15	15	21.3	May 15.

[1] Continued from last month.

[2] Continued at end of month.

[All dates in May unless otherwise specified]

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
EAST GULF DRAINAGE—continued					
Illinois:	*Feet*			*Feet*	
Peru, Ill.	14	(1)	29	20.3	Apr. 2, 3.
Henry, Ill.	10	(1)	24	15.4	Apr. 4.
Peoria, Ill.	18	(1)	14	21.8	Apr. 5, 6, 9.
Havana, Ill.	14	(1)	(2)	19.6	Apr. 6.
Beardstown, Ill.	14	(1)	(2)	21.2	Apr. 6.
Pearl, Ill.	12	(1)	(2)	21.3	Apr. 29–30.
Meramec:					
Steelville, Mo.	12	7	7	13.4	7.
Pacific, Mo.	11	2	10	18.1	9.
		14	16	15.4	16.
		19	22	13.2	21..
Valley Park, Mo.	14	3	10	20.5	8.
		14	22	21.1	16.
Bourbeuse: Union, Mo.	12	4	4	12.2	4.
		8	8	12.1	8.
		20	21	13.9	21.
St. Francis:					
St. Francis, Ark.	18	8	26	25.2	19.
Marked Tree, Ark.	17	25	(2)	17.5	28, 29.
Missouri:					
Hermann, Mo.	21	14	21	24.2	19.
St. Charles, Mo.	25	3	3	25.2	3.
		14	23	30.3	19.
Smoky Hill:					
Mentor, Kans.	22	12	16	25.4	16.
Salina, Kans.	20	----------	----------	22.6	16.
Osage:					
Osceola, Mo.	20	7	10	22.6	8.
		13	27	30.6	21.
Warsaw, Mo.	22	8	8	23.0	8.
		13	26	34.8	19.
Tuscumbia, Mo.	25	9	9	25.7	9.
		14	28	36.9	22.
Arkansas:					
Webbers Falls, Okla.	23	13	23	28.9	15.
Fort Smith, Ark.	22	10	11	22.4	11.
		13	24	29.7	16.
Ozark, Ark.	22	15	23	24.9	17.
Dardanelle, Ark.	20	14	25	26.9	18.
		28	28	20.0	28.
Morrilton, Ark.	20	15	25	26.6	19.
Little Rock, Ark.	23	18	20	23.3	19.
		24	24	23.0	24.
Pine Bluff, Ark.	25	16	27	27.6	20.
Yancopin, Ark.	29	(1)	(2)	44.8	28–30.
Neosho:					
Neosho Rapids, Kans.	22	13	14	25.7	13.
Oswego, Kans.	17	7	7	17.3	7.
		12	21	22.7	13–14.
Wyandotte, Okla.	23	13	15	26.2	14.
		19	20	23.4	19.
Pensacola, Okla.	24	13	15	27.9	14.
		19	20	26.4	20.
Fort Gibson, Okla.	22	10	10	22.7	10.
		13	22	30.0	15.
Verdigris:					
Independence, Kans.	30	8	8	31.6	8.
		12	15	42.5	13.
Sageeyah, Okla.	35	13	19	39.0	18.
Petit Jean: Danville, Ark.	20	20	21	21.8	20.
White:					
Cotter, Ark.	21	9	9	21.0	9.
Calico Rock, Ark.	18	9	11	24.2	9.
Batesville, Ark.	23	9	16	30.6	10.
Newport, Ark.	26	10	19	29.5	12.
Georgetown, Ark.	22	(1)	31	26.3	17, 18.
DeValls Bluff, Ark.	24	(1)	6	26.2	Apr. 22, 23, 25, 26.
		13	29	26.8	May 19–20.
Clarendon, Ark.	30	(1)	4	30.7	Apr. 25–27.
		18	(2)	31.3	May 24, 25.
Black:					
Leeper, Mo.	11	7	7	12.5	7.
Williamsville, Mo.	11	----------	7	12.5	7.
		13	----------	15.6	14,
Poplar Bluff, Mo.	14	8	11	16.3	9.
		14	17	17.8	15.
Corning, Ark.	11	(1)	(2)	13.7	Apr. 16, 17.
		4	31	14.5	May 19.
Black Rock, Ark.	14	(1)	4	22.7	Apr. 11.
		7	(2)	22.3	May 20.
Cache: Patterson, Ark.	9	10	22	10.3	16.
Yazoo: Yazoo City, Miss.	25	(1)	(2)	29.7	1.
Tallahatchie: Swan Lake Miss.	25	(1)	8	31.7	Mar. 29–Apr. 1.
		19	21	25.0	May19–21.
Red:					
Index, Ark.	27	20	22	27.2	21.
Fulton, Ark.	28	19	26	31.1	23.
Sulphur:					
Ringo Crossing, Tex.	20	10	22	24.4	14, 15, 19, 20.
Finley, Tex.	24	17	27	26.4	19.

[All dates in May unless otherwise specified]

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
EAST GULF DRAINAGE—continued					
Ouachita: Arkadelphia, Ark.	*Feet* 12	15	15	*Feet* 14.1	15.
Atchafalaya:					
Simmesport, La.	41	(1)	(2)		
Melville, La.	37	(1)	(2)	43.1	June 9–15.
WEST GULF DRAINAGE					
Neches:					
Rockland, Tex.	22	16	19	23.3	19.
		28	June 6.	26.8	June 1.
Beaumont, Tex.	7	22	24	7.3	23.
		30	June 12.	13.4	June 2.
Sabine:					
Logansport, La.	25	June 10.	June 12.	25.2	June10-11.
Bon Wier, Tex.	20	June 2.	June 3.	20.2	June 3.
Orange, Tex.	4	June 2.	June 5.	4.3	June 4.
Trinity:					
Dallas, Tex.	25	14	(2)	34.5	17.
Trinidad, Tex.	28	17	(2)	39.6	22.
Long Lake, Tex.	40	26	June 12.	45.2	June 3.
Riverside, Tex.	40	31	June 4.	46.2	June 1.
Liberty, Tex.	25	16	(2)	28.3	June 2.
Trinity, Elm Fork: Carrollton, Tex.	7	13	19	9.3	16.
Brazos:					
Valley Junction, Tex.	44	30	30	45.3	30.
Washington, Tex.	45	31	June 5.	51.0	June 1.
Hempstead, Tex.	40	June 1.	June 5.	43.8	June 2.
Rosenberg, Tex.	40	June 3.	June 8.	46.2	June 6.
Freeport, Tex.	4	31	(2)	7.4	June 10.
Colorado:					
Austin, Tex.	18	28	29	25.6	28.
Smithville, Tex.	24	29	31	29.4	30.
Columbus, Tex.	28	29	(2)	37.4	31.
Guadalupe:					
New Braunfels, Tex.	20	29	30	21.8	29.
Gonzales, Tex.	22	26	26	23.7	26.
		29	(2)	34.0	29.
Victoria, Tex.	16	21	21	17.3	21.
		27	(2)	25.7	31.
Nueces:					
Cotulla, Tex.	15	27	29	16.7	27.
Three Rivers, Tex.	37	30	(2)	42.0	31.
Rio Grande: San Marcial, N. Mex.	3	9	(2)	4.2	23–25.
PACIFIC DRAINAGE					
Colorado:					
Grand Junction, Colo.	11	27	27	11.3	27.
Fruita, Colo.	12	22	28	13.5	27.
Parker, Ariz.	7	(1)	(2)	11.9	30.
Colorado, Roaring Fork: Carbondale, Colo.	5	24	26	5.4	26.
Eagle: Eagle, Colo.	5	26	26	5.0	26.
Gunnison: Delta, Colo.	9	8	11	10.2	10.
		14	(2)	11.7	26.
Gunnison, North Fork: Paonia, Colo.	9	10	10	9.0	10.
		15	26	9.5	26.
Green: Elgin, Utah	12	26	31	12.9	30.

[1] Continued from last month.
[2] Continued at end of month.
[3] Below flood stage at 8 a. m., May 1.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, MAY, 1929

By J. B. KINCER

General summary.—Due to persistently cool weather and frequent rains, field work became very backward during the first decade over the eastern half of the country, especially in the central valley States. The latter part was rather favorable, which permitted considerable progress in plowing and planting, but at the same time it was too cool for good germination and growth. There was some local frost damage to fruit and the general wetness was rather unfavorable for pollination. In interior sections farm operations were considerably later than usual, but in the Atlantic Coast States active field work was permitted. Temperatures were favorable in the South and rains in the Southwest were beneficial, although there was some damage by excessive falls in parts.

During the second decade like unfavorable conditions prevailed that had previously retarded growth and work and, consequently, outside operations and growth were again delayed. Rainfall was moderate to light in the

Central-Northern States and field work made better progress in this area, although it was still too cool for good growth and germination of spring planted crops. In Atlantic States conditions were again more favorable, but toward the close of the period it was rather too cool for good growth. Further rains were beneficial in western Texas and New Mexico, while warm, sunny weather favored shearing and lambing in the West.

The weather during the last decade was much better than during the preceding ones, although it continued cool in the East the first part of the period; the fair weather favored field work and vegetation responded rapidly to improved soil conditions. In the interior valleys more favorable weather prevailed and the delayed spring planting made rapid advance, though some lowlands continued too wet. Conditions were irregular in the South, with the first part of the decade too cool and wet in the Southeast and similar conditions in the west Gulf area delayed field operations and crop growth. The weather was favorable in the Great Plains. While rains were helpful in the far Southwest, moisture was badly needed in the interior of the Pacific Northwest.

Small grains.—Winter wheat maintained generally good condition in the Ohio Valley during the first decade, except for some yellowing and local deterioration. Progress and condition varied widely in the trans-Mississippi States, but satisfactory advance was made in the Great Plains; growth was poor to only fair in western Oklahoma and Texas, although good in other parts. Heading was reported northward to Maryland in the East and good advance was made elsewhere, except that rain was needed in the Pacific Northwest. During the second decade the weather was unfavorable for best development in the Ohio Valley and it was too cool for good growth in Iowa. Winter wheat continued in very good condition in the Great Plains with the crop heading in south-central and southeastern Kansas. Progress and condition were fair to very good in the Southwest, and elsewhere mostly satisfactory condition was noted.

During the last decade condition and progress of winter wheat were very good in the Ohio Valley, except for some reports of damage on flooded bottom lands. The dry, warm weather in the trans-Mississippi States was of great benefit, and the crop was in fair to excellent condition in the Great Plains. Rains delayed harvest in Texas, but the moisture was of great benefit in New Mexico; satisfactory condition was reported elsewhere, except that parts of the Pacific Northwest were dry.

Progress and condition of spring wheat were very good in the northern part of the belt, with seeding generally completed during the second decade. Coolness and rain were detrimental to oats during the first two decades, but improvement was noted toward the close of the month. Rice needed rain in Louisiana the early part of the month, but late beneficial showers occurred and excellent progress was being made at the close. Flax planting advanced during the month and rye was in mostly satisfactory condition.

Corn.—Continued cool, wet weather caused considerable delay to corn planting during the first two decades, with little work possible and the delay becoming serious in places. The northwestern belt had somewhat more favorable weather, however, and planting and plowing were rushed whenever possible with considerable time made up, but temperatures were rather too low for good germination. During the last decade the improved weather conditions permitted more active corn planting, and this work was well under way in many of the principal producing sections; considerable lost time was made up, although work was still much behind an average season. In Iowa conditions were mostly favorable and the warmer weather permitted better germination, while in the western belt planting was well advanced.

Cotton.—During the first decade temperatures were rather favorable in the southern portion of the belt, but it was too cool in the north, while heavy rains were unfavorable in many places west of the Mississippi River, especially in northern districts. In the eastern half of the belt the first part was too cloudy and wet, but the latter part was more favorable. Rains were beneficial in Texas, where not excessive, and fair progress was made, although planting and replanting made slow advance. Cool, wet weather delayed germination and growth in Oklahoma, with much to be planted and replanted, while most of Arkansas was also too wet.

The weather continued unfavorable during the second decade, because of too much rain and coolness. Most of the period was rather favorable in Atlantic districts and cotton made fair to fairly good progress in central Gulf sections. In the northwestern belt conditions were decidedly unfavorable, with germination poor and stands irregular; in Texas rains were beneficial in parts, but unfavorable in the east, with chopping and cultivation delayed, although general condition of the crop was fair to good.

Conditions continued rather unfavorable for cotton in the last decade as temperatures in the east were too low for good growth and, although field work made good advance the first part, the latter was too showery, with the crop needing warmth and sunshine. West of the Mississippi River conditions were rather favorable in Arkansas and Louisiana, with progress fair to good, but cool, wet weather in Oklahoma continued detrimental with cotton late, stands poor, and much to be planted and replanted. In Texas rains were of benefit in some southern parts, but it was generally too wet and cold, with planting, replanting, and cultivation at a standstill, and warm, dry weather badly needed.

Miscellaneous crops.—Except for some slow growth, pastures and meadows were generally satisfactory east of the Great Plains and ranges were improving in the northern plains, although there was a local water shortage in Montana at the close. Rains were of benefit in parts of the Southwest, but in the Pacific Northwest ranges were showing the effects of the continued dryness.

Potato planting advanced and the crop generally did well; truck was delayed in some sections by cool weather, but mostly satisfactory condition was reported. Sugar beet seeding was completed with thinning begun in many areas; cane continued excellent advance in Louisiana. Apples dropped badly in parts of the eastern Ohio Valley and Washington toward the close of the month, but otherwise fruits did well rather generally.

WEATHER OF THE ATLANTIC AND PACIFIC OCEANS

NORTH ATLANTIC OCEAN

By F. A. YOUNG

The weather over the greater part of the North Atlantic during May was practically normal and gales were not reported on more than 5 days in any 5° square, the maximum occurring in the square between the forty-fifth and fiftieth parallels and the twenty-fifth and thirtieth meridians.

The Azores HIGH was unusually well developed until the 30th, and the daily barometer readings at Horta were all above the monthly normals until that date; on the 29th it read 30.14, on the 30th, 29.74, and on the 31st, 29.94 inches. Low pressure prevailed over northern Europe during the first half of the month while the last half was characterized by sudden changes.

Fog was observed on from 13 to 18 days over the Grand Banks, from 3 to 5 days off the coast of Europe, and from 1 to 4 days over the northern steamer lanes. No fog reports were received from vessels south of the 35th parallel.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, 8 a. m. (seventy-fifth meridian). North Atlantic Ocean, May, 1929*

Stations	Average pressure	Departure	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	29.77	(1)	30.28	5th	29.20	18th.
Belle Isle, Newfoundland	29.87	[2] −0.07	30.30	21st	28.98	17th.
Halifax, Nova Scotia	30.07	[2] +0.10	30.48	14th	29.70	3d.
Nantucket	30.07	[2] +0.08	30.52	14th	29.26	3d.
Hatteras	30.13	[2] +0.10	30.52	11th	29.68	3d.
Key West	30.05	[2] +0.07	30.16	7th [4]	29.90	2d.
New Orleans	30.05	[2] +0.05	30.20	10th [4]	29.78	1st.
Cape Gracias, Nicaragua	29.90	[2] +0.03	29.96	7th [4]	29.84	26th. [4]
Turks Island	30.12	[2] +0.12	30.20	6th [4]	30.02	30th. [4]
Bermuda	30.30	[2] +0.19	30.44	12th	30.06	3d.
Horta, Azores	30.32	[2] +0.18	30.60	26th	29.64	31st.
Lerwick, Shetland Islands	29.90	[2] +0.10	30.46	29th	29.08	7th.
Valencia, Ireland	29.90	[2] −0.05	30.21	9th	29.44	6th.
London	29.99	[2] +0.07	30.26	29th	29.34	6th.

[1] No normal available.
[2] From normals shown on Hydrographic Office Pilot Chart based on observations at Greenwich mean noon, or 7 a. m., Seventy-fifth meridian time.
[3] From normals based on 8 a. m. observations.
[4] And on other date or dates.

On the 1st a well-defined depression was over the western section of the Gulf of Mexico; on the 2d the center was near Pensacola, on the 3d near New York, and on the 4th over the Gulf of St. Lawrence. This LOW was accompanied by moderate weather except on the evening of the 2d and morning of the 3d; at the time of observation on the latter date moderate to strong gales prevailed along the American coast between Hatteras and Nantucket.

From the 5th to 8th an area of low pressure was over the British Isles, and during this period moderate gales were reported by vessels in the eastern section of the steamer lanes as well as by land stations.

From the 10th to 12th the northeast trades in the vicinity of the Canal Zone were unusually strong, as shown by report in table from the American S. S. *F. Q. Barstow.*

On the 11th moderate gales were encountered over the steamer lanes between the fiftieth and fifty-fifth meridians and on the 12th between the thirtieth and thirty-fifth meridians.

Charts VIII to XI show the conditions over the ocean from the 13th to 16th inclusive.

From the 17th to 21st moderate weather prevailed as a rule, although on the 18th Belle Isle, Newfoundland, reported a westerly wind, force 10.

On the 22d a fairly well-developed disturbance was over Newfoundland and another off the coast of Ireland and moderate gales were reported by vessels in the western and middle sections of the steamer lanes.

On the 23d favorable conditions prevailed, with the exception of a limited disturbance central near 47° N., 15° W.

From the 24th to 29th the weather was comparatively featureless, with high pressure over extensive areas, although during this period some few vessels rendered gale reports.

On the 30th a well-developed LOW was central near 45° N., 35° W.; this moved but little during the next 24 hours and strong westerly gales prevailed in the southerly quadrants on both the 30th and 31st.

OCEAN GALES AND STORMS, MAY, 1929

Vessel	Voyage From—	Voyage To—	Position at time of lowest barometer Latitude	Position at time of lowest barometer Longitude	Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
North Atlantic Ocean			° ′	° ′				*Inches*					
Livenza, Ital. S. S.	Palermo	New York	39 57 N	72 04 W	May 1	11 p, 2	May 3	29.09	SSE	S, 9	S	S, 9	Steady.
Astral, Am. S. S.	Providence	Canal Zone	38 20 N	72 21 W	3	10 a, 3	3	29.11	SW	SW, 10	NW	WSW, 11	Do.
Hellig Olav, Dan. S. S.	Oslo	Halifax	55 35 N	21 40 W	5	8 p, 5	6	29.20	NW	NW, 8	NNW	NW, 9	Do.
Lepanto, Br. S. S.	New York	Hull	49 40 N	7 30 W	5	3 a, 6	6	29.19	NNE	NNW	WNW	NNW, 10	NNW-WNW.
F. Q. Barstow, Am. S. S.	Cartagena	Baltimore	11 38 N	75 30 W	10	4 p, 10	12	29.65	NE	NE, 7	E	NE, 8	NE-E.
Asia, Fr. S. S.	Gibraltar	Providence	38 25 N	59 40 W	10	10 p, 10	11	29.67	SSE	NW, 8	NNE	SW, 9	NW-N-NNE.
Parklaan, Du. S. S.	Rotterdam	Montreal	51 30 N	21 30 W	12	6 p, 12	13	29.22	SSW	NW, 11	WNW	—, 11	SE-NW.
Anacortes, Am. S. S.	Ardrossan	Baltimore	53 30 N	15 00 W	12	2 p, 13	13	28.81	SE	S	S	S, 11	S-SW-W.
Balsam, Am. S. S.	Londonderry	do	46 28 N	37 25 W	12	4 p, 14	17	29.64	WNW	SW, 7	W	—, 10	
Quaker City, Am. S. S.	Middlesbrough.	Philadelphia	51 00 N	34 10 W	15	Noon, 15	16	29.36	SW	SW, 8	WNW	—, 10	Steady.
Nubian, Br. S. S.	Montreal	Avonmouth	51 35 N	14 37 W	21	3 p, 21	21	29.58	S	S, 8	W	S, 9	
E. J. Sadler, Am. S. S.	do	Corpus Christi.	36 25 N	68 50 W	21	1 a, 22	22	29.97	S	SSW, 9	WNW	SSW, 9	SSW-NNW
Davisian, Br. S. S.	Liverpool	Boston	49 06 N	25 23 W	22	Noon, 22	23	29.45	NW	NW, 7	NW	NW, 9	Steady.
Tongking, Dan. M. S.	Antwerp	St. Thomas	47 40 N	12 16 W	22	7 a, 22	24	29.58	SW	SW, 7	WNW	NW, 9	SW-W-NW.
Haarlem, Du. S. S.	Barahona	Holland	49 16 N	21 13 W	21	11 a, 24	24	29.71	NNW	WSW, 3	NNW	NNW, 9	
Tongking, Dan. M. S.	Antwerp	St. Thomas	42 40 N	24 20 W	25	4 a, 25	25	30.06	W	SW, 7	NW	WNW, 9	SW-WNW.
Lubrafol, Belg. S. S.	Port Arthur	Hamburg	43 03 N	41 32 W	30	8 p, 30	31	29.68	WNW	WNW, 9	S	W, 11	WNW-W-S.
Bellflower, Am. S. S.	Manchester	New York	45 48 N	38 01 W	30	4 a, 31	31	28.72	W	W, 9	N	NW, 10	

Ocean gales and storms, May, 1929—Continued

Vessel	Voyage From—	Voyage To—	Position at time of lowest barometer Latitude	Position at time of lowest barometer Longitude	Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
North Pacific Ocean			° ′	° ′				*Inches*					
Shabonee, Br. S. S.	Yokohama	San Pedro	44 30 N	175 10 W	May 3	6 a, 3	May 3	29.53	SSW	SE, 8	SSW	SE, 10	SE-SSW.
Clyde Maru, Jap. S. S.	Miike	Grays Harbor	48 41 N	172 10 W	2	1 a, 3	5	29.08	S	S	SSW	SE, 10	S-SE-SW.
New York, Am. S. S.	Hong Kong	San Francisco	46 10 N	172 31 E	2		5	28.69	S	Calm	W	W, 10	E-O-W.
California, Am. S. S.	Otaru	do	48 00 N	176 50 W	3	4 a, 3	4	28.96	SE	SW, 7	SW	SE, 11	SSW-SW.
Kohnan Maru, Jap. S. S.	Miike	Portland	47 34 N	571 55 E	3	9 p, 3	5	28.65	N	WNW, 9	WSW	WNW, 9	N-W-WSW.
Atlanta City, Am. S. S.	Dairen	Honolulu	31 33 N	129 30 E	6	6	7	29.68	SE	SE, 7	SW	SSW, 9	
Satanta, Br. S. S.	San Pedro	Shanghai	31 00 N	133 30 E	7	7	8	29.82	S	S, 8	W	S, 8	S-SW.
Columbia Maru, Jap. M. S.	Vancouver	Yokohama	50 30 N	179 30 W	10	4 p, 11	11	29.16	S	NNE, 8	N	ENE, 9	NE-NNE-N.
Ryujin Maru, Jap. S. S.	Miike	Vancouver	49 19 N	178 30 W	11	1 p, 11	11	28.83	ESE	NE, 8	NE	NE, 9	Steady.
Toyama Maru, Jap. S. S.	Yokohama	Victoria	50 08 N	167 10 W	11	4 p, 12	12	29.04	E	SE, 2	SSW	E, 9	ESE-E-SE.
Illinois, Am. S. S.	Portland	Shanghai	51 40 N	170 35 W	13	2 a, 13	17	29.01	W	W, 8	WNW	W, 8	W-S-W.
Toba Maru, Jap. S. S.	Yokohama	San Francisco	45 49 N	148 30 W	19	1 a, 20	21	28.88	SE	SE, 8	SW	SE, 8	
Golden Fleece, Am. S. S.	Dairen	do	47 20 N	156 00 W	19	11 p, 19	22	28.94	N	W, 9	W	W, 10	NW-W.
Pennsylvania, Am. S. S.	Hong Kong	do	29 50 N	129 06 E	22	8 a, 22	22	29.57	SE	NE, 8	N	NE, 8	SE-NE-N.
Ixion, Br. S. S.	Yokohama	Victoria	36 51 N	147 02 E	23	Mdt, 24	24	29.28	SE	S, 6	SW	S, 8	Slight.
La Perla, Am. S. S.	San Jose	San Francisco	33 38 N	120 18 W	24	8 a, 24	26	29.93	W	W, 7	NW	NW, 8	W-NW.
Arabia Maru, Jap S. S.	Victoria	Yokohama	53 00 N	158 30 W	25	8 a, 26	27	29.02	ESE	SE, 8	W	W, 8	SE-W.
Sylvan Arrow, Am. S. S.	San Pedro	Balboa	14 34 N	95 41 W	29	2 a, 30	30	29.60	E	ESE, 8	S	ESE, 8	ENE-ESE.
Tuscaloosa City, Am. S. S.	New York	Honolulu	14 28 N	97 26 W	29	2 p, 30	30	29.48	SW	E, 11	NW	E, 11	SSE-E-NE.
Pennsylvanian, Am. S. S.	Los Angeles	New York	15 00 N	97 30 W	30	9 p, 30	31	29.21	SE	NE, 12	SE	NE, 12	NE-SE.
Nebraskan, Am. S. S.	New York	San Francisco	15 05 N	97 42 W	30	Noon, 31	June 1	29.71	SSW	SSW, 8	W	SW, 8	SSW-W.
South Atlantic Ocean													
Ocean Prince, Br. S. S.	Buenos Aires	St. Vincent	34 11 S	52 51 W	8	7 p, 8	May 8	29.65	NNW	NNW	NNW	NNW, 10	Steady.
South Pacific Ocean													
Raisdale, Br. S. S.	Panama	Auckland	33 01 S	148 00 W	5	3 a, 5	5	29.63	WSW	WSW, 7	SW	WSW, 9	Do.
Do	do	do	36 28 S	179 20 E	12	12	14	29.86	E	E, 4	E	E, 9	Do.
Joseph Seep, Am. S. S.	Buenos Aires	Talara	48 40 S	77 20 W	9	7 p, 11	13	29.25	N	W, 2	W	NW, 10	

NORTH PACIFIC OCEAN

By WILLIS E. HURD

Cyclonic conditions over the northern part of the ocean were somewhat brisker in May than in April, and the average atmospheric pressure in the Aleutians and the Bering Sea was lower than in the preceding month, and considerably below the normal. The Aleutian cyclone intensified on the 3d and 4th in upper midocean, and again from the 12th to about the 20th from the Alaskan Peninsula westward. From the 20th to the 23d it affected principally the western waters of the Gulf of Alaska, but thereafter to the end of the month it was shallow and of little influence.

The California-Pacific anticyclone was abnormally well developed practically throughout the month, being little disrupted by low pressure areas coming within its usual boundaries. Anticyclonic conditions on the average extended from the eastern part of the Gulf of Alaska southward and thence westward almost to the Asiatic coast, near which the HIGH was considerably broken by numerous small cyclones that came from the continent or gathered in adjoining waters. At Midway Island the average pressure, 30.19 inches, was the highest in May for many years.

Barometric data for several island and mainland coast stations in west longitudes are given in the following table.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level at indicated hours, North Pacific Ocean and adjacent waters, May, 1929*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Point Barrow [1]			30.48	5th	29.92	8th.
Dutch Harbor [2 3]	29.66	−0.24	30.20	29th	29.06	12th.[4]
St. Paul [2 5]	29.66	−0.20	30.30	29th	28.98	17th.
Kodiak [2]	29.83	−0.04	30.40	12th	29.06	22d.
Midway Island [2 3]	30.19	+0.10	30.34	26th	29.98	29th.
Honolulu [6]	30.05	0.00	30.16	16th	29.91	28th.
Juneau [6]	30.08	+0.09	30.38	10th	29.69	24th.
Tatoosh Island [6 7]	30.11	+0.07	30.47	9th	29.71	30th.
San Francisco [6 7]	30.00	+0.02	30.19	8th	29.79	26th.
San Diego [6 7]	29.94	+0.01	30.13	8th	29.69	26th.

[1] For 18 days, no average computed.
[2] P. m. observations only.
[3] For 29 days.
[4] And on other dates.
[5] For 30 days.
[6] A. m. and p. m. observations.
[7] Corrected to 24-hour mean.

Gales of force 8 and upward occurred on about 15 days of the month, being of about the same frequency as in April, although less widely distributed over the usual stormy portions of the sea. Strong to whole gales, however, were more frequent along the northern steamer routes than in the preceding month, partly owing to the greater fluctuating developments of the Aleutian LOW; so, although the month can hardly be called a stormy one, its weather was rougher over portions of the trans-Pacific passages than that of April.

Few traveling cyclones of more than very moderate intensity appeared on the North Pacific during May. In extratropical waters a cyclone that first appeared as a depression in eastern China on the 20th, developed some intensity south of Japan on the 22d, causing fresh northeasterly gales over the eastern part of the Yellow Sea. On the 23d the storm deepened as it skirted the Japanese east coast, although still no gales higher than fresh were reported. On the 24th to 26th, continuing barometrically low, it moved north-northeastward across the Kuril Islands and entered the Bering Sea, where it merged with the Aleutian cyclone. In tropical waters the only typhoon of the month, and not of great severity, is described in a following article by the Rev. José Coronas, of the Philippine Weather Bureau.

From May 29 to June 1 a tropical cyclone existed south and west of the Gulf of Tehuantepec. Little is known of its activities beyond the fact that it attained great violence on the 30th and was apparently traveling west-northwestward not far from the Mexican coast. During the afternoon of the 29th the American steamer *Sylvan Arrow*, southbound, ran across the northern edge of the storm southwest of the gulf, experiencing moderate to fresh easterly gales, with slight depression of the barometer, the greatest depth, 29.70 inches, occurring on the morning of the 30th, in 14° 34′ N., 95° 41′ W. The American steamer *Tuscaloosa City*, Colon to Honolulu, encountered an east gale of force 11 at 1.30 p. m. of the 30th, barometer 29.48, in 14° 28′ N., 97° 26′ W., and the S. S. *Pennsylvania* had a northeast hurricane, lowest pressure 29.21 inches, at 8.30 p. m., in 15° 00′ N., 97° 30′ W. The S. S. *Nebraskan*, northbound, reported "continuous heavy rain from noon, May 30, to 4 a. m. June 1, wind increasing to whole gale force at times."

This is the second May cyclone in these waters of which the Weather Bureau has record; it is also the only hurricane of the month, the earlier being the moderate disturbance of May 24–27, 1928.

The weather at Honolulu was drier and warmer than usual for the month. The trades blew during 90 per cent of the time, with winds from the east prevailing. The highest velocity was at the rate of 23 miles an hour from the northeast, on the 14th.

As summer conditions began settling in on the Pacific, fog increased in area and in number of days of formation over upper latitudes and locally in lower latitudes. This increase in May was especially pronounced along the American coast and over a great region generally southeast of the Kuril Islands. East of northern Japan for an approximate distance of 1,000 miles at sea fog became more and more frequent as the month wore on, the percentage of days with it for the entire period rising to 30 or 35 in some 5° squares. Twenty per cent of the days were foggy off the central California coast, and along the western length of Lower California to and below Cape San Lucas, fog was reported on 9 days, mostly during the early half of the month.

Note.—American steamer *President Taft*, Capt. K. A. Ahlin, Yokohama to Victoria, May 24–June 2. Observer, B. H. Bassett, third officer: "This trip has been very unusual in having continuous overcast weather. Southerly winds with fog and southeasterly winds with rain predominated. No wind from the north quadrants were experienced after leaving the Japanese coast."

Typhoon in the North Pacific Ocean, April, 1929.—According to a clipping from the San Diego Union, of May 24 (San Diego, Calif.), the American steamer *Edgefield*, Capt. W. H. Walker, experienced a heavy typhoon "near the Philippines" on April 25, 1929, with the barometer down to 28.10 and the wind blowing at 115 miles an hour. The paper quoted Captain Walker as saying:

"The emergency steering gear and all movable equipment on the deck was carried away. Electric light wiring to the deck house was torn away and the radio room destroyed. Paint was blown off the ventilators, and an intense feeling of suffocation was felt while the ship floundered around in the vortex of the gale."—*W. E. Hurd.*

Mirage in the Red Sea.—The following communications from observers on board vessels bound from the Indian Ocean toward Suez relate to special atmospheric conditions experienced in and near the Red Sea.

Dutch cargo steamer *Stadsdijk*, Capt. D. C. Wijers, observer K. Rodenhuis: "On May 4, in the Gulf of Suez, we perceived much looming of ships, lighthouses, and coast in the neighborhood. After sunset the lights of Ras Gharib, Zafarana, and Abu Deraj were seen at twice their usual distance. The barometer followed its daily alterations. Temperature of air was 28° (82° F.), and of sea water at surface 24° to 22° (75° to 72° F.). No wind observable."

British steamer *Donax*, Captain and observer C. Howe: "May 5, abnormal refraction. At 2100 light E'ly airs and heavy dew. The Brothers Light (Red Sea) was sighted bearing 323° dist. 54′. This light disappeared at 2104 until 2120. The light was then in sight continuously, varying from full brilliancy to a loom. At this time it was impossible to get even an approximation of the horizon, sky and sea appearing to run into one."—*W. E. Hurd.*

TYPHOONS AND DEPRESSIONS

By Rev. José Coronas, S. J.

[Weather Bureau, Manila, P. I.]

The first typhoon over the Philippines in 1929.[1]—The first typhoon of 1929 [1] did not appear clearly in our weather maps until 6 a. m. of May 24, when it was only 100 miles east of Samar, thus giving rather a short time for proper warnings. Its center traversed Samar Island moving WNW. or NW. by W. during the night of May 24 to 25, and reached the Strait of San Bernardino in the early morning of the 25th. From the Strait of San Bernardino it continued moving WNW. until the afternoon of the 25th, when it began to move northward across the Ragay Gulf. This northerly direction was kept until after midnight when it inclined again northwestward traversing with this direction the northernmost part of Luzon on the 26th. Then, on the 27th it recurved to ENE. and E. by N. across the Balintang Channel.

It was not a severe typhoon, the barometric minimum so far reported from our stations being that of Guiuan 747.51 mm. (29.31 ins., not corrected for gravity) at 4.30 p. m. of the 24th.

The approximate positions of the center at 6 a. m. of May 24 to 28 were as follows:

May 24, 127° 30′ long. E.; 11° 25′ lat. N.
May 25, 124° 30′ long. E.; 12° 25′ lat. N.
May 26, 122° 00′ long. E.; 17° 05′ lat. N.
May 27, 123° 30′ long. E.; 20° 00′ lat. N.
May 28, 129° 10′ long. E.; 20° 05′ lat. N.

Due probably to local conditions, even though the center of the typhoon did not touch the Province of Leyte, reports have been received of extensive damage done to the crops by heavy rains and floods with loss of over 100 lives in several towns of the southern part of that Province.

[1] A press report, quoted in the preceding article, indicates the occurrence of a typhoon at the end of April, but no other information regarding such a storm has been received to date by the Weather Bureau.—*W. E. H.*

CLIMATOLOGICAL TABLES[1]

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation, by sections, May, 1929

Section	Temperature								Precipitation					
	Section average	Departure from the normal	Monthly extremes						Section average	Departure from the normal	Greatest monthly		Least monthly	
			Station	Highest	Date	Station	Lowest	Date			Station	Amount	Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	71.3	0.0	3 stations	96	[2]12	2 stations	37	[2]2	5.86	+1.89	Wetumpka	10.83	Robertsdale	2.28
Arizona	68.0	+0.7	Parker	106	10	Alpine	10	1	0.15	−0.17	Alpine	2.04	33 stations	0.00
Arkansas	67.6	−1.4	2 stations	97	31	2 stations	30	3	6.31	+1.29	Wynne	11.52	Princeton	1.98
California	61.6	+1.2	Greenland Ranch	110	25	Twin Lakes	7	12	0.09	−1.00	Ellery Lake	2.26	112 stations	0.00
Colorado	51.7	−0.9	Las Animas	94	19	Dillon	2	1	1.61	−0.19	Cuchara Camps	4.01	Rugh Ranch	0.15
Florida	76.6	+1.0	2 stations	99	[2]8	Plant City	41	4	4.98	+1.00	Fort Pierce	11.09	Long Key	1.15
Georgia	71.6	0.0	2 stations	97	[2]29	Clayton	34	4	5.48	+1.98	Resaca	10.21	Lumber City	0.66
Idaho	52.9	−0.6	Grand View	99	22	Big Springs	10	1	0.55	−0.99	Grangerville	2.52	6 stations	0.00
Illinois	60.1	−2.5	Mt. Carmel	95	30	Aurora	27	4	5.81	+1.81	Casey	11.89	La Salle	1.23
Indiana	59.6	−2.6	Edwardsport	96	30	Howe	28	20	7.13	+3.12	Salem	11.58	Whiting	2.41
Iowa	57.7	−2.4	2 stations	91	[2]28	3 stations	24	[2]2	2.47	−2.11	Riverton	5.79	Chariton	0.82
Kansas	61.2	−2.2	Oketo	94	29	Hays	27	2	4.76	+1.01	Chanute	12.34	Gove (near)	1.42
Kentucky	64.2	−1.1	Quicksand	98	29	Maysville	32	3	7.33	+3.33	2 stations	11.21	Munfordville	4.86
Louisiana	74.0	+0.4	Hammond	96	31	2 stations	38	3	6.08	+1.65	Crowley	13.35	Burwood	1.28
Maryland-Delaware	62.1	−0.5	Frederick, Md.	96	31	Oakland, Md.	26	17	3.08	−0.51	Maryland Line, Md.	6.89	Millington, Md.	1.31
Michigan	51.5	−2.4	Deer Park	96	29	Wolverine	14	20	3.69	+0.57	Lowell	7.69	Cheboygan	0.89
Minnesota	51.1	−3.3	Hallock	95	25	Meadowlands	12	16	2.01	−1.02	Worthington	4.71	Mahnomen	0.55
Mississippi	72.3	+1.0	Aberdeen	100	1	Port Gibson	37	3	4.76	+0.30	Merrill	9.32	Rosedale	1.03
Missouri	61.7	−2.9	3 stations	94	[2]29	Goodland	28	3	7.52	+2.82	Lamonte	13.68	Grant City	1.45
Montana	49.7	−1.4	Glendive	97	24	Harlowton	7	12	1.71	−0.57	Baker	6.24	Eunis	0.26
Nebraska	57.4	−1.6	McCook	98	14	2 stations	22	2	2.73	−0.82	Pawnee City	7.98	Hull (near)	0.80
Nevada	56.9	+0.6	Logandale	103	24	Rye Patch	15	[2]1	0.14	−0.66	Sharp	0.72	10 stations	0.00
New England	55.7	+0.8	Rockport, Mass.	98	29	Pittsburg (a), N. H.	21	10	4.13	+0.72	Pittsburg (b), N. H.	6.80	Pittsfield, Mass.	2.67
New Jersey	59.9	−0.2	2 stations	95	31	Layton	26	10	3.49	−0.26	South Orange	5.58	Cape May City	1.26
New Mexico	58.1	−1.0	2 stations	99	15	Selsor Ranch	8	2	2.60	+1.33	Gallinas Planting Station.	7.54	Hachita	0.02
New York	55.4	−0.4	Walden	98	30	2 stations	22	10	4.47	+0.93	North Lake	7.62	Brockport	1.94
North Carolina	66.4	0.0	Louisburg	92	31	Mount Mitchell	19	3	6.33	+2.30	Murphy	11.25	Settle	2.76
North Dakota	49.1	−3.5	McKinney	92	13	McKinney	8	5	2.99	+0.44	Marmarth	7.29	Melville	0.65
Ohio	58.5	−1.5	Fremont	96	30	Millport	26	10	5.33	+1.74	Mount Healthy	9.63	Madison	3.05
Oklahoma	65.8	−2.2	Miami	93	29	Boise City	27	2	7.67	+3.30	McAlester	16.25	Boise City	1.68
Oregon	54.2	+0.5	Huntington	98	24	Lake	10	7	0.98	−0.85	Cruzatte	5.23	5 stations	T.
Pennsylvania	58.5	−1.0	Lock Haven	97	30	3 stations	23	[2]10	4.81	+0.82	Clearfield	8.43	Philadelphia Navy Yard.	1.96
South Carolina	69.1	−1.8	Garnett	94	16	Caesar's Head	32	3	6.46	+2.81	Rimini	4.03	Beaufort (near)	1.13
South Dakota	54.4	−1.4	2 stations	93	24	Camp Crook	15	6	2.66	−0.32	Marion	5.58	La Delle	0.97
Tennessee	66.5	−0.2	Newbern	96	31	4 stations	35	[2]3	7.69	+3.49	Pheasant Field	14.99	Dover	4.05
Texas	72.1	−1.0	Eagle Pass	108	5	Muleshoe	26	2	7.70	+4.04	Rockland	22.55	Grand Falls	0.65
Utah	55.1	−0.1	St. George	98	24	Woodruff	17	11	0.47	−0.74	Elkhorn (Ashley)	1.91	7 stations	0.00
Virginia	63.7	+0.1	Lincoln	95	31	Burkes Garden	28	22	4.77	+0.92	Dante	9.80	Quantico	1.58
Washington	54.4	+0.3	Wahluke	97	22	4 stations	24	[2]1	1.51	−0.62	Baker Lake	5.87	Wapato	0.07
West Virginia	60.8	−1.4	Charleston	98	31	Ryan	23	8	5.81	+1.88	Camden-on-Gauley	11.14	Romney	2.25
Wisconsin	52.1	−2.7	High Falls	94	30	2 stations	16	[2]9	2.39	−1.50	Brule Island	6.33	Prairie du Sac	0.84
Wyoming	47.2	−2.0	Barnum	92	24	Dome Lake	−5	1	2.04	−0.10	Rocky Point	6.09	Sage	0.12
Alaska	28.5	−0.7	Akiak	74	25	Tanana	−29	3	1.57	−0.35	Kalsin Bay	9.99	Skagway	0.16
Hawaii	73.1	+1.2	Waialua Mill	92	26	Volcano Observatory.	48	10	4.16	−2.01	2 stations	17.20	Moaula	0.00
Porto Rico	76.2	−1.0	Comerio	92	3	Jayuya	55	2	8.75	+1.76	Canovanas	17.38	Ponce	2.03

[1] For description of tables and charts, see REVIEW, January, p. 36.

[2] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, May, 1929*

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F		°F	°F		°F	°F	°F	°F	%	In.	In.		Miles								0–10	In.	In.
New England							55.9	+1.3										72	3.81	+0.6										5.5		
Eastport	76	67	85	29.92	30.00	+0.04	48.6	+0.9	82	29	57	34	20	41	34	44	39	73	3.28	+0.3	14	7,253	s.	34	nw.	16	6	5	20	7.0	T.	0.0
Greenville, Me	1,070	6	----	28.83	29.99	------	51.3	------	89	29	63	28	14	39	40	----	----	14	5.40	------	14	5,788	nw.	36	------	16	9	6	16	----	T.	0.0
Portland, Me	103	82	117	29.92	30.04	+.07	54.6	+1.3	90	30	64	38	9	45	29	48	43	69	3.54	+0.1	12	6,607	sw.	36	s.	3	14	6	11	4.8	0.0	0.0
Concord	289	70	79	29.71	30.02	+.04	56.7	+2.4	95	30	71	29	10	43	44	----	----	----	4.30	+1.3	12	4,458	nw.	30	w.	5	15	11	5	4.3	0.0	0.0
Burlington	403	11	48	29.56	30.00	+.03	54.2	−2.3	92	30	65	31	10	44	33	----	----	----	4.51	+1.7	13	7,140	s.	37	sw.	14	7	5	19	7.0	T.	0.0
Northfield	876	12	60	29.07	30.02	+.05	52.2	−0.6	91	30	66	25	10	38	44	48	42	68	2.72	0.0	12	4,881	s.	40	s.	3	5	14	12	6.5	T.	0.0
Boston	125	115	188	29.90	30.03	+.05	61.0	+3.9	96	30	72	42	10	50	38	53	47	64	2.82	−0.4	10	6,948	sw.	34	se.	3	8	17	6	5.2	0.0	0.0
Nantucket	12	14	90	30.05	30.06	+.07	54.5	+2.2	84	31	61	42	9	48	26	50	47	82	4.10	+1.2	12	12,129	sw.	44	s.	3	9	13	9	5.4	0.0	0.0
Block Island	26	11	46	30.02	30.05	+.06	54.3	+1.5	81	31	60	42	10	48	24	50	48	82	4.81	+1.3	13	11,823	sw.	48	w.	16	7	16	8	5.3	0.0	0.0
Providence	160	215	251	29.88	30.05	+.07	59.6	+1.1	94	30	70	41	10	49	36	52	45	63	3.45	+0.5	11	8,368	n.	52	n.	16	12	13	6	4.9	0.0	0.0
Hartford	159	122	----	29.88	30.06	+.08	59.7	+2.2	92	30	71	39	10	49	37	----	----	----	4.41	+0.8	13	------	sw.	----	------	----	12	10	9	4.9	0.0	0.0
New Haven	106	74	153	29.95	30.06	+.07	59.2	+1.3	93	31	69	41	8	49	38	53	49	75	3.94	+0.2	13	6,614	s.	35	sw.	16	8	15	8	5.7	0.0	0.0
Middle Atlantic States							61.4	−0.5										72	3.81	+0.3									5.7		
Albany	97	107	115	29.93	30.03	+.05	58.4	−0.9	92	30	69	37	10	48	34	53	50	75	2.34	−0.6	13	5,115	sw.	26	sw.	1	15	10	6	4.5	0.0	0.0
Binghamton	871	10	84	29.11	30.04	+.06	56.2	−1.2	91	30	68	31	10	44	39	----	----	----	5.55	+2.2	15	4,210	nw.	31	sw.	2	4	15	12	6.4	0.0	0.0
New York	314	414	454	29.73	30.07	+.08	60.6	0.0	90	31	70	42	8	52	34	53	47	68	3.64	+0.4	15	11,098	sw.	62	w.	16	6	10	15	6.6	0.0	0.0
Bellefonte	1,050	5	36	28.95	30.06	------	55.8	------	94	30	69	28	10	43	42	52	48	75	4.41	------	16	------	w.	----	------	----	7	11	13	6.2	0.0	0.0
Harrisburg	374	94	104	29.68	30.08	+.10	60.8	−1.0	91	31	71	38	10	51	32	54	48	66	4.14	+0.7	13	4,628	s.	30	nw.	16	10	9	12	5.8	0.0	0.0
Philadelphia	114	123	367	29.96	30.09	+.10	62.8	−0.1	92	31	72	44	8	53	31	57	54	76	2.28	−1.0	15	9,770	sw.	45	s.	3	8	8	15	6.1	0.0	0.0
Reading	325	81	98	29.72	30.07	------	61.4	------	93	31	72	39	4	51	34	54	48	66	3.48	−0.2	14	4,487	sw.	25	w.	16	9	11	11	5.7	0.0	0.0
Scranton	805	111	119	29.21	30.07	+.09	58.2	−1.2	92	30	69	33	10	47	35	52	46	68	3.70	+0.4	14	5,031	sw.	33	nw.	16	6	10	15	6.5	0.0	0.0
Atlantic City	52	37	172	30.03	30.09	+.11	58.0	−0.1	85	16	64	43	10	52	37	54	50	78	1.90	−1.2	12	12,153	s.	50	s.	2	8	15	8	5.0	0.0	0.0
Cape May	17	13	49	----	----	------	58.8	+0.2	81	31	67	41	10	51	30	55	52	80	1.26	------	10	------	s.	----	------	----	11	9	11	----	0.0	0.0
Sandy Hook	22	10	55	30.01	30.06	------	59.6	------	91	31	67	43	4	52	31	54	50	76	4.86	+1.1	15	9,521	sw.	44	w.	16	8	9	14	5.9	0.0	0.0
Trenton	190	159	183	29.86	30.06	------	61.6	------	91	31	72	41	4	51	35	55	50	70	3.53	+0.4	15	7,355	sw.	39	nw.	16	8	9	14	6.1	0.0	0.0
Baltimore	123	100	215	29.94	30.07	+.08	64.3	−0.1	95	31	74	43	4	55	33	57	52	67	1.78	−1.8	14	7,022	sw.	42	sw.	3	11	9	11	5.7	0.0	0.0
Washington	112	62	85	29.95	30.07	+.07	64.5	+0.8	92	31	75	42	17	54	31	57	52	68	2.29	−1.4	15	3,968	s.	28	w.	3	10	8	13	5.5	0.0	0.0
Cape Henry	18	8	54	30.07	30.09	------	65.8	------	90	16	74	47	11	58	30	60	56	75	6.73	+3.2	11	8,341	sw.	37	e.	9	14	8	9	5.2	0.0	0.0
Lynchburg	681	153	188	29.35	30.09	+.09	65.3	−2.0	91	31	77	42	17	54	32	58	54	71	3.06	−0.6	15	5,374	sw.	36	s.	2	5	19	7	5.7	0.0	0.0
Norfolk	91	170	205	30.01	30.11	+.11	66.6	+0.4	86	28	75	49	4	58	27	60	56	73	7.90	+4.1	14	9,219	sw.	57	w.	19	12	7	12	5.5	0.0	0.0
Richmond	144	11	52	29.94	30.09	+.10	65.8	−0.7	88	31	76	45	17	56	31	59	55	74	4.00	+0.2	14	5,718	sw.	39	w.	3	12	14	5	4.7	0.0	0.0
Wytheville	2,304	49	55	27.73	30.08	+.09	59.8	−1.6	86	31	71	36	3	48	36	54	51	75	3.64	0.0	19	3,984	w.	32	w.	2	6	16	9	5.9	T.	0.0
South Atlantic States							69.7	−0.4										76	5.20	+1.7									5.6		
Asheville	2,253	70	84	27.77	30.10	+.11	62.2	−0.4	83	31	72	38	3	53	33	56	53	78	5.16	+1.7	16	5,702	se.	35	s.	2	6	17	8	5.7	T.	0.0
Charlotte	779	55	62	29.27	30.10	+.11	68.7	−0.2	89	31	79	43	3	58	30	60	56	71	5.90	+2.3	12	2,979	sw.	24	w.	16	7	11	13	6.1	0.0	0.0
Greensboro	886	5	56	29.16	30.11	------	65.5	------	88	31	77	42	23	54	33	59	56	77	3.88	------	13	6,010	sw.	35	w.	2	8	6	17	6.6	0.0	0.0
Hatteras	11	11	50	30.10	30.10	+.10	69.6	+0.9	82	27	75	55	3	64	17	65	62	76	4.86	+1.2	11	8,661	sw.	46	w.	3	13	12	6	4.2	0.0	0.0
Raleigh	376	103	110	29.70	30.10	+.11	67.6	−0.9	88	13	78	45	3	58	28	61	58	76	6.05	+2.2	13	5,098	sw.	36	se.	29	7	9	15	6.0	0.0	0.0
Wilmington	78	81	91	30.05	30.13	+.12	69.6	−1.2	85	25	78	48	10	61	23	65	63	81	5.25	+1.8	11	5,009	sw.	35	sw.	2	12	11	8	5.0	0.0	0.0
Charleston	48	11	92	30.07	30.12	+.11	72.0	−0.7	89	7	78	50	3	66	23	67	64	76	4.30	+1.3	9	7,146	s.	36	s.	2	10	13	8	4.9	0.0	0.0
Columbia, S. C	351	41	57	29.74	30.12	+.12	70.6	−1.3	88	15	80	47	3	61	32	64	61	78	5.49	+2.4	13	4,739	s.	37	s.	2	9	14	8	5.3	0.0	0.0
Due West	711	10	55	29.37	30.14	------	68.2	------	85	16	78	42	3	59	30	----	----	----	4.99	------	12	5,730	sw.	40	w.	2	6	11	14	6.4	0.0	0.0
Greenville, S. C	1,039	139	146	29.01	30.10	------	67.4	+0.2	87	31	76	42	3	58	29	60	56	73	3.66	−0.4	16	5,562	s.	42	w.	2	8	11	12	6.0	0.0	0.0
Augusta	182	62	77	29.90	30.09	+.10	72.2	−0.2	91	18	83	48	3	62	33	64	60	72	6.85	+3.8	13	3,494	s.	30	sw.	2	7	16	8	5.6	0.0	0.0
Savannah	65	150	194	30.05	30.12	+.12	72.7	−0.7	89	7	80	50	3	65	24	67	64	78	3.65	+0.6	8	7,534	se.	42	w.	2	10	11	10	5.5	0.0	0.0
Jacksonville	43	209	245	30.05	30.10	+.10	74.6	−0.4	89	17	82	51	3	68	23	68	65	76	6.09	+2.1	10	7,614	e.	46	sw.	2	10	12	9	5.2	0.0	0.0
Florida Peninsula							78.9	+1.6										74	5.73	+1.5									4.6		
Key West	22	10	64	30.02	30.04	+.07	80.4	+1.3	89	20	86	69	10	75	17	73	71	74	5.95	+2.4	17	7,743	e.	22	nw.	3	16	13	2	3.7	0.0	0.0
Miami	25	71	164	30.06	30.08	+.08	78.2	+1.8	87	2	82	67	3	74	16	72	70	74	6.96	+0.7	17	7,841	e.	31	s.	2	6	18	7	5.8	0.0	0.0
Tampa	35	79	87	30.04	30.08	+.09	78.0	+1.7	92	10	87	54	4	69	25	70	67	75	4.27	+1.3	11	4,569	e.	24	sw.	2	8	18	5	5.1	0.0	0.0
Titusville	44	5	----	30.05	30.10	------	77.0	------	94	2	85	50	4	69	29	----	----	----	7.20	------	9	------	s.	----	------	----	19	9	3	3.9	0.0	0.0
East Gulf States							72.5	0.0										78	5.18	+1.3									5.7		
Atlanta	1,173	190	216	28.87	30.10	+.11	68.8	−1.1	89	30	77	42	3	60	24	63	60	77	6.10	+2.6	11	6,704	s.	42	w.	2	7	10	14	6.2	0.0	0.0
Macon	370	78	87	29.70	30.10	+.11	72.2	−0.1	90	15	82	45	4	62	28	64	60	69	2.52	−0.4	10	4,188	s.	31	sw.	2	11	6	14	5.5	0.0	0.0
Thomasville	273	49	58	29.80	30.09	+.10	74.0	0.0	92	30	84	49	3	64	27	67	63	74	3.92	+0.3	8	3,032	e.	19	sw.	2	4	18	9	6.3	0.0	0.0
Apalachicola	36	42	49	30.04	30.06	------	74.4	------	88	30	80	54	3	69	21	70	68	79	2.15	−1.2	7	5,470	se.	24	w.	2	16	12	3	3.8	0.0	0.0
Pensacola	56	149	185	30.01	30.07	+.08	74.6	+0.7	86	31	78	56	3	71	20	70	68	82	2.06	−1.3	5	9,678	s.	56	sw.	2	5	11	15	6.4	0.0	0.0
Anniston	741	9	57	29.32	30.10	+.11	68.8	+0.4	92	30	79	39	3	58	30	----	----	----	6.25	+2.3	15	3,089	se.	21	sw.	2	14	8	9	4.8	0.0	0.0
Birmingham	700	11	48	29.32	30.08	+.10	70.0	−1.1	92	31	79	42	3	61	29	64	61	79	10.20	+6.2	15	4,694	se.	24	w.	2	9	6	16	6.2	0.0	0.0
Mobile	57	125	161	30.00	30.06	+.07	74.8	+0.4	94	31	82	51	3	68	27	69	67	82	5.21	+0.9	9	7,189	s.	27	se.	31	7	15	9	5.5	0.0	0.0
Montgomery	223	100	112	29.83	30.08	+.09	72.8	−0.6	93	30	82	49	3	64	26	66	63	76	7.27	+3.4	11	4,612	se.	27	sw.	2	9	12	10	5.8	0.0	0.0
Corinth	469	6	----	----	----	------	70.0	------	95	31	80	42	3	60	31	----	----	----	8.46	------	15	------	s.	----	------	----	3	24	4	----	0.0	0.0
Meridian	375	87	95	29.65	30.04	+.06	72.6	+1.3	92	31	81	44	3	64	26	66	63	77	5.55	+1.2	11	4,037	s.	25	w.	2	6	9	16	6.4	0.0	0.0
Vicksburg	247	65	73	29.78	30.06	+.09	72.5	−0.4	90	31	81	47	3	64	28	66	62	78	3.32	−1.0	12	4,646	se.	30	s.	1	8	14	9	5.5	0.0	0.0
New Orleans	53	76	84	29.99	30.04	+.07	76.2	+0.8	94	31	84	57	2	69	22	70	68	82	7.62	+3.0	15	4,255	se.	22	sw.	18	5	13	13	6.5	0.0	0.0
West Gulf States							72.2	−1.2										77	8.96	+4.9									6.0		
Shreveport	249	77	93	29.74	30.01	+.06	72.5	−1.1	91	31	82	51	2	64	32	66	63	80	3.48	−0.7	13	4,432	se.	28	nw.	1	7	16	8	5.7	0.0	0.0
Bentonville	1,303	11	44	28.64	29.99	+.06	62.9	−3.5	86	31	72	39	2	53	32	----	----	----	9.23	------	16	3,981	s.	27	se.	9	18	9	4	----	0.0	0.0
Fort Smith	457	79	94	29.51	29.99	+.06	67.2	−2.4	88	31	76	41	3	58	37	61	58	76	•7.10	+2.3	11	5,465	e.	62	nw.	1	6	9	16	6.8	0.0	0.0
Little Rock	357	136	153	29.64	30.01	+.06	67.7	−2.6	91	31	77	41	3	59	32	61	58	76	6.20	+1.4	14	6,233	s.	34	w.	1	3	12	16	7.0	0.0	0.0
Austin	605	136	148	29.31	29.94	------	74.0	−0.6	98	1	84	45	3	64	43	66	62	74	12.75	+8.1	14	6,295	se.	45	nw.	1	5	12	14	6.2	0.0	0.0
Brownsville	57	83	100	29.86	29.92	------	78.7	+0.1	90	24	85	60	3	72	20	71	69	80	8.60	+6.3	8	8,884	se.	32	n.	2	9	17	5	4.9	0.0	0.0
Corpus Christi	20	11	78	29.92	29.94	+.04	77.4	+1.2	89	1	82	57	2	72	22	72	70	82	5.34	+2.1	9	9,552	se.	33	nw.	2	6	6	19	7.3	0.0	0.0
Dallas	512	220	227	29.42	29.96	------	70.4	------	90	8	79	48	2	62	39	----	----	----	10.38	+5.9	14	9,377	se.	68	w.	1	10	12	9	5.2	0.0	0.0
Fort Worth	670	106	114	29.24	29.94	+.03	70.8	−1.5	90	5	80	48	2	62	39	63	59	73	5.83	+1.2	15	6,956	se.	36	nw.	1	5	7	19	6.7	0.0	0.0
Galveston	54	106	114	29.94	30.00	+.06	74.6	−0.2	82	17	79	53	2	70	19	70	68	83	10.50	+7.1	11	9,405	se.	37	nw.	2	8	15	8	5.4	0.0	0.0
Groesbeck	461	11	56	29.48	29.95	------	71.7	------	93	1	80	44	3	63	42	----	----	----	16.59	+12.5	14	8,117	se.	36	nw.	1	5	16	10	6.0	0.0	0.0
Houston	138	292	314	29.85	29.99	------	74.0	−1.5	89	8	82	51	2	66	21	----	----	----	12.03	+7.5	13	9,451	se.	39	nw.	1	7	12	12	5.9	0.0	0.0
Palestine	510	64	72	29.46	29.99	+.06	71.1	−1.6	89	8	80	47	3	62	40	65	62	77	8.55	+4.0	14	5,624	s.	32	nw.	1	6	9	16	6.6	0.0	0.0
Port Arthur	34	58	66	29.96	30.00	------	75.0	------	87	31	81	51	2	69	20	----	----	----	6.47	------	10	5,607	se.	28	s.	26	10	11	10	5.3	0.0	0.0
San Antonio	693	119	132	29.21	29.93	+.03	74.7	−0.4	99	1	85	48	3	64	44	66	62	73	7.73	+4.5	14	5,665	se.	38	nw.	1	6	15	10	5.5	0.0	0.0
Taylor	583	55	63	29.38	29.99	+.08	72.8	−1.5	98	1	83	47	3	63	46	----	----	----	10.34	+6.3	12	6,098	se.	34	nw.	1	5	17	9	5.8	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations May, 1929*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
Ohio Valley and Tennessee	*Ft.*	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	*° F.* 62.7	*° F.* −2.2	*°F.*		*°F.*	*° F.*		*° F.*	*° F.*	*° F.*	*° F.*	*%* 72	*In.* 6.90	*In.* +3.1		*Miles*									*0–10* 6.4	*In.*	*In.*
Chattanooga	762	190	215	29.27	30.08	+.09	67.8	−1.0	90	31	77	40	2	59	35	60	56	72	12.00	+8.2	15	5,114	se.	34	sw.	2	4	14	13	6.2	0.0	0.0
Knoxville	995	102	111	29.03	30.08	+.09	66.2	−1.0	88	28	76	40	2	57	32	60	56	74	7.66	+3.9	14	4,523	sw.	37	sw.	2	3	14	14	6.9	0.0	0.0
Memphis	399	76	97	29.61	30.03	+.07	68.8	−1.8	92	30	77	44	2	60	30	62	59	74	4.88	+0.7	14	5,170	sw.	37	w.	2	5	9	17	6.7	0.0	0.0
Nashville	546	168	191	29.50	30.08	+.10	66.6	−1.6	91	31	76	41	3	57	33	60	55	71	6.46	+2.6	12	6,251	s.	38	nw.	2	7	11	13	6.2	0.0	0.0
Lexington	989	193	230	29.02	30.09	+.10	62.2	−2.1	88	30	72	33	2	53	35	----	----	----	5.59	+1.8	13	8,685	sw.	46	sw.	2	9	11	11	5.4	T.	0.0
Louisville	525	188	234	29.50	30.08	+.10	63.6	−3.0	91	30	73	36	2	55	30	57	54	75	7.16	+3.4	15	6,962	n.	39	w.	2	8	8	15	6.2	0.0	0.0
Evansville	431	76	116	29.62	30.08	+.11	63.8	−2.9	92	30	72	35	2	55	29	58	54	75	6.27	+2.4	14	5,937	s.	35	sw.	2	8	10	13	6.2	T.	0.0
Indianapolis	822	194	230	29.18	30.06	+.09	59.4	−3.5	89	30	68	34	2	51	27	53	48	70	8.46	+4.6	16	7,515	s.	42	nw.	2	6	11	14	6.4	0.2	0.0
Royal Center	736	11	55	29.26	30.07	------	56.0	------	87	29	66	32	2	46	30	----	----	----	4.82	+0.8	12	7,055	s.	46	w.	11	4	15	12	6.5	0.3	0.0
Terre Haute	575	96	129	29.44	30.06	------	60.1	------	88	30	69	34	2	51	34	54	50	73	8.95	+5.1	11	6,342	s.	31	w.	15	6	13	12	6.5	T.	0.0
Cincinnati	627	11	51	29.40	30.08	+.09	60.6	−2.5	90	30	70	35	2	51	33	55	51	75	7.74	+4.0	16	4,471	sw.	27	sw.	2	8	8	15	6.4	T.	0.0
Columbus	822	179	222	29.20	30.08	+.10	59.7	−2.6	89	30	69	33	2	51	33	54	49	71	4.55	+1.0	16	6,736	nw.	42	w.	3	9	11	11	5.6	T.	0.0
Dayton	899	137	173	29.11	30.06	------	60.0	−2.6	92	30	69	33	2	51	30	54	49	72	7.41	+3.8	16	5,799	sw.	36	sw.	2	7	12	12	6.4	T.	0.0
Elkins	1,947	59	67	28.05	30.08	+.08	57.6	−1.6	84	26	69	30	17	46	43	53	49	77	8.09	+4.0	23	3,819	w.	30	w.	2	3	7	21	7.9	T.	0.0
Parkersburg	637	77	82	29.43	30.09	+.10	61.6	−2.2	89	27	72	38	3	51	35	54	49	69	5.02	+1.6	19	3,678	nw.	27	w.	3	8	7	16	6.6	T.	0.0
Pittsburgh	842	353	410	29.16	30.06	+.07	59.5	−2.9	93	30	69	33	3	50	34	53	47	67	5.38	+2.2	16	6,811	sw.	40	w.	3	6	12	13	6.3	T.	0.0
Lower Lake Region							55.5	−1.9										71	3.81	+0.6										5.8		
Buffalo	767	247	280	29.20	30.03	+.06	52.8	−1.8	86	27	61	34	4	45	30	48	44	75	2.79	−0.3	14	11,016	sw.	58	w.	3	7	15	9	5.5	T.	0.0
Canton	448	10	61	29.51	29.99	------	53.6	−2.6	88	28	64	33	20	43	31	----	----	----	4.04	+1.0	12	7,482	w.	48	sw.	3	11	8	12	5.8	T.	0.0
Ithaca	836	5	100	29.14	30.05	------	53.8	------	89	30	62	30	10	42	40	49	45	72	5.47	+2.1	16	6,016	nw.	40	se.	2	5	7	19	6.5	T.	0.0
Oswego	335	76	91	29.66	30.03	+.06	52.6	−2.6	82	30	62	33	20	44	33	48	42	69	4.03	+1.0	13	5,906	w.	34	w.	16	7	11	13	6.0	T.	0.0
Rochester	523	88	102	29.47	30.05	+.08	55.6	−1.5	92	30	66	34	4	45	31	48	42	64	2.20	−0.7	15	5,764	w.	36	w.	16	7	13	11	6.2	T.	0.0
Syracuse	596	65	79	29.40	30.04	+.06	56.4	−0.9	90	30	66	35	10	47	33	----	----	----	3.61	+0.6	15	5,015	s.	26	sw.	16	5	12	14	6.4	T.	0.0
Erie	714	130	166	29.28	30.06	+.08	55.9	−0.9	87	30	64	35	20	47	32	50	45	71	3.89	+0.5	12	8,150	w.	43	sw.	3	9	15	7	4.9	T.	0.0
Cleveland	762	190	201	29.24	30.06	+.08	56.4	−1.5	87	30	64	34	3	48	32	50	45	67	3.41	+0.3	14	7,510	sw.	40	w.	16	7	16	8	5.7	T.	0.0
Sandusky	629	5	67	29.39	30.07	+.09	57.0	−2.2	89	30	66	35	8	48	36	----	----	----	4.43	+1.3	16	5,960	sw.	33	nw.	3	4	15	12	6.0	T.	0.0
Toledo	628	208	243	29.38	30.07	+.10	57.0	−2.4	91	30	66	34	2	48	32	51	46	69	3.62	+0.1	15	9,012	sw.	40	sw.	11	13	10	8	4.7	0.0	0.0
Fort Wayne	856	113	124	29.13	30.06	------	57.4	−2.8	89	29	67	34	3	48	29	52	47	72	4.69	+0.8	13	6,187	sw.	32	ne.	2	5	15	11	6.1	T.	0.0
Detroit	730	218	258	29.27	30.06	+.09	56.2	−1.8	92	29	66	35	3	47	29	51	49	80	3.59	+0.4	12	7,031	sw.	38	nw.	16	10	8	13	5.9	T.	0.0
Upper Lake Region							50.6	−2.1										69	2.92	−0.3										5.4		
Alpena	609	13	92	29.37	30.04	+.07	47.8	−2.7	89	30	57	31	9	39	36	43	37	67	3.84	+0.8	9	7,870	nw.	44	nw.	16	11	14	6	4.8	9.7	0.0
Escanaba	612	54	60	29.37	30.04	+.07	46.9	−2.7	83	30	55	30	16	39	32	42	37	70	2.25	−0.7	8	7,276	s.	35	n.	16	12	8	11	4.8	0.3	0.0
Grand Haven	632	54	89	29.36	30.05	+.09	51.4	−3.1	83	29	60	33	3	43	29	47	42	71	3.88	+0.7	8	7,094	s.	37	w.	15	7	17	7	5.5	T.	0.0
Grand Rapids	707	70	87	29.29	30.06	+.09	54.8	−3.2	88	29	65	32	2	45	34	48	42	63	6.31	+2.9	10	4,276	w.	27	w.	16	8	8	15	6.2	2.0	0.0
Houghton	668	64	99	29.28	30.01	+.04	48.0	−1.5	85	28	58	27	15	38	34	----	----	----	1.96	−1.1	10	7,708	sw.	35	w.	4	8	12	11	5.9	5.1	0.0
Lansing	878	6	49	29.11	30.06	------	53.7	−3.2	86	29	64	30	8	43	34	49	45	73	3.98	+0.6	11	4,235	w.	29	w.	11	9	13	9	5.4	2.6	0.0
Ludington	637	60	66	29.34	30.04	------	48.6	------	79	29	56	32	16	41	31	46	43	80	2.46	−0.6	7	6,977	s.	29	sw.	11	11	13	7	4.6	T.	0.0
Marquette	734	77	111	29.22	30.03	+.06	48.7	−0.3	91	29	58	27	16	40	33	43	36	63	2.59	−0.4	10	7,967	nw.	37	sw.	22	9	8	14	6.1	8.0	0.0
Port Huron	638	70	120	29.35	30.05	+.08	52.8	−2.4	89	29	62	33	8	44	32	47	42	69	2.56	−0.4	9	8,066	ne.	40	n.	2	8	18	5	4.5	T.	0.0
Sault Sainte Marie	614	11	52	29.33	30.03	+.08	56.5	−2.5	86	29	56	26	16	37	34	41	36	72	3.15	+0.1	12	6,415	nw.	32	nw.	3	10	13	8	5.0	7.9	0.0
Chicago	673	7	131	29.34	30.06	+.10	56.8	−0.7	90	29	65	35	3	48	36	51	45	69	2.29	−1.2	8	7,393	sw.	35	sw.	15	7	9	15	6.4	T.	0.0
Green Bay	617	109	141	29.36	30.03	+.08	51.8	−3.1	86	29	62	28	15	42	49	47	42	70	1.70	−1.8	9	7,852	s.	33	sw.	15	8	11	12	5.8	0.1	0.0
Milwaukee	681	125	221	29.32	30.05	+.09	53.0	−1.1	87	28	63	33	3	43	39	46	40	65	2.01	−1.3	7	8,465	w.	38	sw.	15	11	8	12	5.2	T.	0.0
Duluth	1,122	5	47	28.80	30.04	+.08	46.2	−1.1	81	28	56	20	16	36	38	40	34	66	1.97	−1.3	8	8,371	nw.	30	nw.	15	12	10	9	4.9	1.1	0.0
North Dakota							49.4	−4.6										58	2.15	−0.4										4.1		
Moorhead	940	50	58	29.00	30.02	+.08	50.6	−4.5	87	25	63	23	5	38	42	43	34	57	1.13	−1.8	6	6,920	n.	25	sw.	29	14	12	5	4.0	T.	0.0
Bismarck	1,674	8	57	28.20	30.00	+.08	51.2	−3.3	81	13	64	23	5	38	44	43	34	59	2.37	0.0	9	6,941	n.	32	n.	29	12	14	5	4.1	1.0	0.0
Devils Lake	1,478	11	44	28.43	30.02	+.08	47.2	−5.4	87	25	60	17	5	34	41	40	32	60	2.17	+0.1	8	7,407	nw.	28	n.	15	16	10	5	4.1	T.	0.0
Ellendale	1,457	10	56	28.46	30.02	------	50.8	------	85	25	64	22	6	38	42	----	----	----	1.42	−1.7	11	10,384	nw.	49	sw.	29	12	12	7	4.4	0.5	0.0
Grand Forks	833	12	67	----	----	----	49.2	------	89	25	62	20	5	36	41	43	----	----	2.31	------	5	------	nw.	----	s.	13	19	7	5	----	T.	0.0
Williston	1,878	41	48	28.02	30.01	+.08	48.8	−5.2	86	24	62	20	6	36	41	41	31	57	3.64	+1.6	9	5,831	n.	27	se.	9	17	8	6	3.9	0.7	0.0
Upper Mississippi Valley							58.3	−3.1										67	3.61	−0.4										5.9		
Minneapolis	918	102	208	29.02	30.01	------	54.8	−2.9	89	28	65	29	3	45	32	----	----	----	1.91	−1.8	9	8,186	s.	27	se.	10	13	11	7	4.7	0.2	0.0
St. Paul	837	236	261	29.13	30.04	+.10	54.2	−3.7	86	28	64	28	3	44	31	----	----	----	1.97	−1.3	9	8,588	se.	34	sw.	22	12	10	9	4.9	T.	0.0
La Crosse	714	11	48	29.26	30.03	+.09	55.5	−3.8	87	28	66	32	4	45	33	49	41	62	3.39	−0.4	10	3,358	nw.	15	n.	2	12	7	12	5.2	0.0	0.0
Madison	974	70	78	29.01	30.06	+.10	54.6	−3.0	85	29	64	32	3	45	42	48	41	64	1.31	−2.5	10	5,679	nw.	26	s.	15	11	8	12	5.3	0.0	0.0
Wausau	1,247	4	64	28.70	30.02	------	52.0	------	86	28	63	28	19	40	40	----	----	----	3.04	−0.6	8	4,844	w.	22	sw.	22	13	8	10	4.8	0.3	0.0
Charles City	1,015	10	51	28.97	30.04	+.11	54.8	−3.0	87	28	66	30	3	44	33	49	43	64	3.24	−1.1	11	4,562	se.	30	n.	1	13	9	9	4.6	0.0	0.0
Davenport	606	71	79	29.39	30.05	+.10	59.6	−1.7	89	28	69	34	3	50	42	53	48	70	1.23	−2.7	8	6,892	nw.	33	nw.	15	7	11	13	6.2	0.0	0.0
Des Moines	861	84	97	29.12	30.03	+.10	59.2	−2.1	87	28	69	33	5	50	31	52	46	64	2.18	−2.4	11	5,055	n.	20	sw.	22	4	11	16	6.8	0.0	0.0
Dubuque	700	81	96	29.30	30.05	+.10	56.8	−3.5	87	29	67	33	3	47	40	50	42	61	1.39	−2.8	8	4,308	nw.	23	ne.	2	8	8	15	6.6	T.	0.0
Keokuk	614	64	78	29.39	30.06	+.12	60.4	−3.4	87	28	70	37	16	51	42	53	48	66	2.97	−1.0	15	4,643	s.	25	sw.	11	3	12	16	7.1	0.0	0.0
Cairo	358	87	93	29.67	30.05	+.09	65.5	−2.9	90	30	74	39	2	57	25	59	56	75	5.19	+1.5	13	6,234	s.	37	nw.	2	4	8	19	7.3	0.0	0.0
Peoria	609	11	45	29.41	30.07	+.11	59.4	−2.3	90	29	69	34	5	50	43	53	47	68	5.03	+1.0	14	4,337	s.	28	sw.	11	5	16	10	5.9	T.	0.0
Springfield, Ill.	636	154	191	29.38	30.06	+.11	59.0	−4.2	88	29	68	32	2	50	38	54	50	73	6.32	+1.9	14	8,291	s.	39	w.	15	3	16	12	6.7	0.6	0.0
Hannibal	534	74	109	29.46	30.04	+.10	60.8	−2.8	88	29	70	38	16	52	42	----	----	----	4.92	+0.6	16	5,920	sw.	35	w.	15	4	12	15	6.9	0.0	0.0
St. Louis	568	265	303	29.44	30.05	+.10	62.2	−4.7	90	30	71	32	2	54	32	56	52	73	10.09	+5.8	15	7,988	s.	38	n.	2	9	10	12	5.9	4.0	0.0
Missouri Valley							59.2	−2.2										66	4.94	+1.0										5.8		
Columbia, Mo.	784	6	84	29.20	30.03	+.09	61.0	−3.3	88	15	70	36	5	52	40	----	----	----	11.98	+7.5	18	5,055	e.	26	n.	2	6	8	17	6.7	0.0	0.0
Kansas City	963	161	181	28.99	30.02	+.10	61.2	−3.6	84	28	69	36	2	53	37	55	50	71	6.91	+2.3	14	6,628	e.	37	n.	1	4	14	13	6.4	0.0	0.0
St. Joseph	967	11	49	28.99	30.02	------	61.4	------	86	28	71	36	2	52	34	54	49	70	3.72	−0.5	12	5,470	se.	34	nw.	15	5	12	14	6.3	0.0	0.0
Springfield, Mo.	1,324	98	104	28.63	30.03	+.10	61.1	−3.4	85	31	70	32	2	52	32	56	52	76	9.77	+4.6	15	7,060	se.	30	nw.	2	13	9	9	5.0	6.1	0.0
Iola	984	11	50	28.96	30.00	+.08	61.6	−3.6	84	29	71	37	2	52	34	----	----	----	8.05	+3.4	16	4,380	s.	25	n.	1	6	10	15	6.6	0.0	0.0
Topeka	987	92	107	----	----	----	61.2	−3.1	83	24	70	35	2	52	34	----	----	----	5.96	+1.5	13	6,502	ne.	31	n.	2	7	7	17	6.4	0.0	0.0
Lincoln	1,189	11	81	28.75	30.01	+.10	60.0	−1.7	85	30	70	33	2	50	33	53	47	66	3.28	−0.8	9	6,564	s.	34	nw.	15	6	9	16	6.4	0.0	0.0
Omaha	1,105	115	122	28.85	30.02	+.10	60.8	−1.0	86	28	70	33	2	52	26	52	46	63	2.02	−1.8	11	5,306	se.	30	nw.	15	6	14	11	6.0	0.0	0.0
Valentine	2,598	47	54	27.29	30.00	+.10	55.5	−0.7	85	14	67	29	16	44	47	47	39	60	3.08	+0.3	16	6,976	n.	36	sw.	29	14	7	10	4.8	7.0	0.0
Sioux City	1,135	94	164	28.82	30.03	+.11	58.6	−1.8	88	30	69	29	2	48	34	50	43	62	1.73	−2.3	7	8,030	s.	37	nw.	15	7	16	8	5.7	0.0	0.0
Huron	1,306	59	74	28.63	30.04	+.12	55.2	−1.2	86	22	68	29	2	43	41	47	39	60	1.17	−1.8	7	7,020	s.	33	n.	15	16	9	6	4.0	T.	0.0
Pierre	1,572	70	75	------	30.00	+.09	56.6	−1.4	87	22	69	30	5	44	51	----	----	62	1.66	−0.5	10	6,944	se.	40	ne.	28	16	9	6	----	T.	0.0
Yankton	1,233	49	57	28.71	30.03	+.11	57.7	−1.7	88	14	70	28	2	46	37	----	----	----	4.94	+1.1	6	5,272	se.	26	nw.	15	5	17	9	5.9	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, May, 1929*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	° F.	° F.	°F.		°F.	°F.		°F.	°F.	° F.	° F.	%	In.	In.		Miles								0–10	In.	In.
Northern Slope							51.0	−1.8										59	1.94	−0.5										5.3		
Billings	3,140	5					52.8		91	23	70	16	8	35	55				1.25		7		nw.				12	10	9			0.0
Havre	2,505	11	44	27.35	29.99	+0.09	52.0	−1.4	86	23	66	24	6	38	40	43	34	61	1.90	−0.1	11	4,646	e.	40	sw.	24	12	10	9	5.1	T.	0.0
Helena	4,110	87	112	25.79	29.98	+.05	50.6	−1.0	84	22	63	26	15	38	36	43	37	66	0.88	−1.4	11	5,695	sw.	28	sw.	24	6	12	13	6.4	2.1	0.0
Kalispell	2,973	48	56	26.90	29.95	+.07	50.9	−0.5	83	31	63	29	6	39	37	42	32	55	0.69	−0.8	9	4,113	nw.	22	ne.	14	9	13	9	5.3	0.0	0.0
Miles City	2,371	48	55	27.47	30.02	+.11	53.3	−3.4	92	24	66	26	6	41	39	44	33	54	2.24	0.0	9	3,646	ne.	29	nw.	14	12	12	7	4.5	T.	0.0
Rapid City	3,259	50	58	26.60	30.01	+.11	52.0	−2.0	86	24	64	31	8	41	49	44	35	64	1.46	−1.0	10	8,232	s.	39	w.	26	7	8	16	6.4	0.5	0.0
Cheyenne	6,088	84	101	24.00	29.95	+.10	48.0	−2.3	75	14	60	24	1	36	37	40	34	64	1.46	−0.4	5	3,967	w.	52	sw.	14	14	12	5	4.0	3.8	0.0
Lander	5,372	60	68	24.63	29.96	+.08	50.6	−0.6	83	23	64	25	6	37	41	41	32	57	1.84	−0.4	5	3,967	w.	52	sw.	14	12	15	4	4.8	3.4	0.0
Sheridan	3,790	10	47	26.10	29.99		50.4		89	24	65	22	8	36	46	42	33	60	2.55	−0.1	11	3,814	nw.	35	nw.	14	12	15	4	4.0	3.8	0.0
Yellowstone Park	6,241	11	48	23.88	29.99	+.08	43.7	−3.7	76	23	56	22	8	31	39	35	27	57	1.04	−1.2	11	4,987	sw.	32	sw.	24	5	13	13	6.2	9.4	0.0
North Platte	2,821	11	51	27.07	29.98	+.10	57.5	−1.2	90	14	69	30	2	46	41	49	43	65	2.58	−0.2	10	5,590	s.	27	nw.	15	11	11	9	5.3	0.0	0.0
Middle Slope							60.2	−2.3										68	4.06	+0.5										6.5		
Denver	5,292	106	113	24.72	29.95	+.11	54.4	−1.8	82	14	66	29	1	43	35	44	35	55	1.65	−0.6	12	5,224	s.	32	n.	5	8	10	13	5.7	0.4	0.0
Pueblo	4,685	80	86	25.27	29.91	+.08	59.0	−0.2	85	14	72	30	2	46	44	46	36	52	1.11	−0.5	8	4,819	e.	26	s.	26	8	14	9	5.3	0.0	0.0
Concordia	1,392	50	58	28.56	30.03	+.12	60.0	−3.2	83	27	69	34	2	51	30	55	51	74	3.56	−0.6	13	5,752	s.	23	nw.	15	2	12	17	7.3	0.0	0.0
Dodge City	2,509	11	51	27.41	29.99	+.12	61.1	−2.4	87	27	71	32	2	51	34	54	49	74	2.61	−0.3	10	7,296	se.	30	se.	26	7	12	12	5.9	0.0	0.0
Wichita	1,358	139	158	28.56	29.99	+.09	61.8	−3.3	82	29	70	36	2	54	26	56	53	77	5.84	+1.4	15	8,469	s.	34	s.	11	7	11	13	6.4	0.0	0.0
Broken Arrow	765	11	56	29.17	30.00		64.0		83	15	72	41	2	56	32				7.02	+2.3	14	8,765	s.	42	n.	1	3	9	19	7.7	T.	0.0
Oklahoma City	1,214	10	47	28.70	29.97	+.08	64.7	−3.0	85	15	73	40	1	56	33	59	55	78	6.67	+1.8	12	6,595	s.	40	nw.	17	4	11	16	7.1	0.0	0.0
Southern Slope							68.3	−2.3										62	3.53	+0.8										5.7		
Abilene	1,738	10	52	28.14	29.92	+.05	70.4	−1.6	98	5	81	44	2	60	38	60	53	64	4.22	+0.3	11	7,461	se.	32	nw.	1	7	10	14	6.4	0.0	0.0
Amarillo	3,676	10	49	26.26	29.95	+.11	61.8	−2.3	87	27	72	34	2	51	38	54	50	71	3.19	+0.4	12	7,040	s.	26	nw.	1	6	10	15	6.4	T.	0.0
Del Rio	944	64	71	28.90	29.87	+.02	75.9	−1.1	101	4	86	53	2	66	41	65	58	60	4.41	+1.5	9	7,217	se.	46	nw.	17	8	13	10	5.3	0.0	0.0
Roswell	3,566	75	85	26.32	29.88	+.06	65.2	−4.2	93	10	78	31	2	52	46	52	41	53	2.30	+1.2	7	6,272	s.	33	nw.	1	13	10	8	4.6	0.0	0.0
Southern Plateau							66.6	+1.2										37	1.43	+1.1										2.6		
El Paso	3,778	152	175	26.12	29.83	+.05	71.1	−0.4	95	10	84	43	2	58	37	52	32	35	1.51	+1.2	10	8,895	e.	46	nw.	17	21	10	0	2.4	0.0	0.0
Santa Fe	7,013	38	53	23.24	29.84	+.03	54.2	−1.5	78	10	66	23	2	42	40	43	32	52	5.58	+4.3	13	4,921	se.	33	ne.	16	12	10	9	4.9	0.2	0.0
Flagstaff	6,907	10	59	23.33	29.82	+.04	51.4	+0.7	75	9	68	22	2	35	46	39		45	0.38				sw.		sw.	26	17	10	4		T.	0.0
Phoenix	1,108	10	107	28.65	29.78	.00	78.0	+3.0	100	19	94	51	2	62	42	54	30	21	0.01	−0.1	1	4,308	w.	24	w.	11	29	2	0	2.4	0.0	0.0
Yuma	141	9	54	29.64	29.78	−.01	78.2	+2.0	102	18	96	52	28	60	44	57	36	30	0.02	0.0	1	3,456	w.	27	n.	11	29	2	0	0.7	0.0	0.0
Independence	3,957	6	27	25.91	29.89	+.05	66.6	+3.6	92	24	82	40	27	51	41	46			0.05	−0.1	1		nw.				18	9	4		0.0	0.0
Middle Plateau							57.3	+1.4										41	0.16	−0.8										4.3		
Reno	4,532	74	81	25.44	29.90	−.01	57.6	+4.0	86	22	73	31	1	42	43	43	29	40	0.01	−0.6	1	5,266	w.	33	w.	4	16	13	2	3.8	T.	0.0
Tonopah	6,090	12	20																												
Winnemucca	4,344	18	56	25.60	29.96	+.05	55.6	+1.7	88	23	72	26	1	39	46	43	33	52	0.06	−0.8	2	4,731	ne.	25	nw.	2	13	17	1	3.9	T.	0.0
Modena	5,473	10	43	24.55	29.83	+.01	55.2	+1.7	83	24	72	26	1	38	43	40	21	31	0.09	−0.7	5	7,408	w.	42	sw.	25	11	14	6	4.4	T.	0.0
Salt Lake City	4,360	163	203	25.57	29.90	+.04	58.2	+0.8	86	24	69	34	26	48	31	45	31	39	0.18	−1.7	2	5,146	nw.	27	e.	20	13	9	9	4.7	T.	0.0
Grand Junction	4,602	60	68	25.32	29.86	+.03	60.0	−1.1	85	30	73	33	1	47	38	46	32	43	0.45	−0.4	8	4,309	se.	29	sw.	31	12	11	8	4.9	0.0	0.0
Northern Plateau							56.7	+0.5										59	0.54	−1.0										5.1		
Baker	3,471	48	53	26.45	30.03	+.07	51.0	−0.7	85	22	65	30	1	37	43	41	31	53	0.59	−1.0	7	4,232	se.	22	sw.	23	9	10	12	5.7	T.	0.0
Boise	2,739	78	86	27.13	29.98	+.04	57.8	+0.7	89	22	71	32	10	45	37	48	39	55	0.14	−1.3	2	4,222	nw.	29	e.	23	9	17	5	4.7	0.0	0.0
Lewiston	757	40	48	29.20	30.01	+.05	60.2	+0.7	93	21	74	37	1	46	47				0.56	−1.0	8	2,674	e.	25	nw.	24	10	8	13	5.7	0.0	0.0
Pocatello	4,477	60	68	25.43	29.93	+.04	54.0	+0.2	82	23	67	27	1	41	41	41	28	43	0.40	−1.1	6	5,737	se.	30	sw.	3	9	18	4	4.8	T.	0.0
Spokane	1,929	101	110	27.95	29.99	+.03	56.8	+1.3	88	21	69	35	7	44	39	45	34	50	0.72	−0.7	5	4,295	s.	27	sw.	24	9	12	10	5.2	0.0	0.0
Walla Walla	991	57	65	28.94	30.00	+.04	60.4	+0.8	89	21	72	41	26	49	36	48	37	47	0.80	−0.8	8	3,316	s.	23	w.	24	14	10	7	4.5	0.0	0.0
North Pacific Coast Region							53.8	+0.2										68	1.20	−0.9										5.8		
North Head	211	11	56	29.92	30.15	−.12	49.6	+1.3	68	17	53	43	1	46	13	47	45	87	1.20	−1.8	11	10,258	n.	40	s.	23	4	20	7	5.6	0.0	0.0
Port Angeles	20	8	58		30.12		50.0		66	22	58	37	3	42	25				0.62	−0.7	6	5,060	sw.	29	nw.	24	10	8	13		0.0	0.0
Seattle	125	215	250	29.95	30.08	+.07	54.6	+0.1	76	19	63	42	1	46	26	48	43	68	1.48	−0.4	13	5,062	s.	33	sw.	24	6	11	14	5.9	0.0	0.0
Tacoma	194	172	201	29.89	30.10	+.08	54.4	+0.3	78	19	63	40	1	46	29				1.58	−0.5	13	5,192	w.	29	sw.	24	5	13	13	6.2	0.0	0.0
Tatoosh Island	86	9	53	30.01	30.11	+.10	49.2	−0.4	68	18	53	42	12	46	12	47	46	92	2.77	−1.2	6	6,299	sw.	34	s.	23	3	5	23	8.0	0.0	0.0
Yakima	1,076	58	67	28.86	30.01		60.2		89	21	73	38	3	47	39	47	33	43	0.18	−0.4	2	4,812	nw.	25	w.	2	10	11	10	5.3	0.0	0.0
Medford	1,425	4	80	28.52	30.02		58.0		91	21	75	31	7	41	49	47	38	58	0.41		5		nw.	19	ne.	25	17	9	5	3.8	0.0	0.0
Portland, Oreg	153	68	106	29.92	30.09	+.06	58.6	+1.7	82	19	68	43	14	49	31	50	44	63	1.14	−1.0	13	3,475	nw.	24	w.	31	6	8	17	6.7	T.	0.0
Roseburg	510	75	99	29.54	30.09	+.06	56.6	+0.6	87	11	70	35	7	43	45	48	40	63	0.65	−1.3	7	2,992	n.	18	w.	23	11	14	6	4.9	0.0	0.0
Middle Pacific Coast Region							60.4	+0.5										66	0.08	−0.9										3.7		
Eureka	62	73	89	30.04	30.11	+.06	51.6	+0.4	62	2	56	41	27	47	19	48	46	83	0.14	−1.7	5	5,131	n.	26	n.	26	11	7	13	5.5	0.0	0.0
Red Bluff	330	54	58	29.58	29.93	−.02	69.0	+2.7	102	21	84	46	6	54	43	54	39	41	0.12	−1.0	1	4,309	n.	23	nw.	25	18	8	5	3.3	0.0	0.0
Sacramento	69	106	117	29.85	29.93	−.01	64.5	+1.2	89	11	78	45	5	50	35	54	45	59	0.04	−0.7	1	6,192	s.	31	nw.	26	25	6	0	1.5	0.0	0.0
San Francisco	155	208	243	29.83	30.00	+.01	56.5	−0.3	81	11	63	47	6	50	31	51	48	79	0.01	−0.8	1	6,085	w.	30	w.	4	12	10	9	5.0	0.0	0.0
San Jose	141	12	110	29.84	30.00		60.2	−0.5	91	11	73	40	6	47	46				0.11	−0.4	1	4,291	nw.	29	nw.	26	21	6	4	3.0	0.0	0.0
South Pacific Coast Region							65.7	+2.3										61	0.02	−0.4										3.3		
Fresno	327	89	98	29.56	29.91	−.01	69.4	+2.3	96	22	84	47	6	54	36	54	40	42	0.01	−0.4	1	5,713	nw.	30	nw.	31	20	9	2	2.2	0.0	0.0
Los Angeles	338	159	191	29.59	29.96	+.01	65.0	+2.8	91	12	74	52	8	56	32	56	50	66	T.	−0.4	0	3,488	sw.	18	sw.	12	15	13	3	3.8	0.0	0.0
San Diego	87	62	70	29.85	29.94	−.01	62.7	+1.9	87	2	69	52	8	57	28	56	52	74	0.05	−0.3	2	4,506	w.	18	nw.	12	16	10	5	3.8	0.0	0.0
West Indies																															
San Juan, P. R.	82	9	54	29.94	30.03		76.8	−1.8	87	30	81	67	28	72	14				7.97	+3.2	20	9,961	e.	28	e.	19	9	14	8	5.7	0.0	0.0
Panama Canal																															
Balboa Heights	118	7	97	[1] 29.74	[2] 29.83	.00	81.2	+0.5	93	13	88	72	20	74	19			[2] 82	4.04	−3.7	20	4,228	nw.	21	nw.	13	0	10	21	8.3	0.0	0.0
Cristobal	38	7	97	[1] 29.81	[2] 29.84	.00	81.7	+1.0	90	21	87	74	8	77	15	77	75	[2] 83	10.07	−2.3	23	,333	n.	23	n.	11	1	11	19	7.7	0.0	0.0
Alaska																															
Juneau	80	11	50	[1] 29.99	[1] 30.08		47.2		67	6	55	33	30	39	20	42	36	70	4.74		15	4,484	e.	19	e.	18	8	6	17	6.4	0.0	0.0
Hawaiian Islands																															
Honolulu	38	86	100	[1] 30.01	[1] 30.05		75.4		83	20	80	67	8	71	14	68	64	70	0.77	−1.0	11	6,056	e.	23	ne.	14	13	13	5	4.5	0.0	0.0

[1] Pressure not reduced to mean of 24 hours.

[2] Observations taken bihourly.

TABLE 2.—*Data furnished by the Canadian Meteorological Service, May, 1929*

Stations	Altitude above mean sea level Jan. 1, 1919	Pressure			Temperature of the air						Precipitation		
		Station reduced to mean of 24 hours	Sea level reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Mean maximum	Mean minimum	Highest	Lowest	Total	Departure from normal	Total snowfall
	Feet	*Inches*	*Inches*	*Inches*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*Inches*	*Inches*	*Inches*
Cape Race, N. F.	99				40.3		48.0	32.7	58	28	7.05		0.0
Sydney, C. B. I.	48	29.98	30.03	+0.06	46.7	+1.5	56.5	36.9	70	30	4.52	+0.75	1.0
Halifax, N. S.	88	29.94	30.05	+.07	50.4	+2.0	60.2	40.7	87	34	4.85	+0.59	0.0
Yarmouth, N. S.	65	29.91	29.98	.00	48.3	+0.7	55.5	41.2	71	33	4.31	+0.74	0.0
Charlottetown, P. E. I.	38	29.90	29.94	−.02	48.0	+1.1	55.4	40.6	77	30	4.68	+1.77	3.0
Chatham, N. B.	28	29.87	29.90	−.05	47.9	−0.6	58.1	37.7	82	27	3.15	−0.06	0.0
Father Point, Que.	20												
Quebec, Que.	296	29.64	29.96	+.02	50.2	+0.3	59.5	40.9	86	31	5.29	+2.21	0.7
Doucet, Que.	1,236				45.0		59.1	30.9	88	6	3.83		1.0
Montreal, Que.	187	29.75	29.96	+.02	54.3	−0.4	63.5	45.1	91	36	5.21	+2.26	T.
Ottawa, Ont.	236	29.71	29.97	+.03	54.3	−0.6	65.2	43.4	93	33	3.32	+0.73	T.
Kingston, Ont.	285	29.70	30.01	+.05	50.4	−2.5	57.6	43.2	78	34	3.52	+0.84	0.0
Toronto, Ont.	379	29.61	30.02	+.04	53.0	−0.2	62.1	43.8	91	33	3.77	+0.73	0.1
Cochrane, Ont.	930				43.3		53.8	32.8	88	16	4.61		21.2
White River, Ont.	1,244	28.65	29.98	+.03	41.7	−4.0	54.0	29.5	87	15	2.51	+0.56	8.0
London, Ont.	808				53.0		64.4	41.5	90	28	5.86		T.
Southampton, Ont.	656	29.31	30.03	+.07	47.9	−2.8	57.1	38.7	82	28	5.86	+3.42	T.
Parry Sound, Ont.	688	29.31	30.01	+.06	48.3	−2.8	57.5	39.1	80	30	4.24	+1.31	1.7
Port Arthur, Ont.	644	29.30	30.01	+.05	44.6	−1.3	54.1	35.2	74	19	1.28	−0.87	5.0
Winnipeg, Man.	760												
Minnedosa, Man.	1,690	28.20	30.04	+.08	45.5	−2.9	57.5	33.5	77	17	1.02	−0.43	1.5
Le Pas, Man.	860				43.7		57.0	30.4	79	18	0.25		T.
Qu'Appelle, Sask.	2,115	27.76	30.02	+.08	44.2	−5.6	56.2	32.2	75	15	1.91	+0.26	4.1
Moose Jaw, Sask.	1,759				47.9		62.3	33.5	85	11	1.73		3.7
Swift Current, Sask.	2,392	27.44	29.97	+.05	48.4	−2.3	64.0	32.8	90	10	2.23	+0.47	2.6
Medicine Hat, Alb.	2,144												
Calgary, Alb.	3,428												
Banff, Alb.	4,521												
Prince Albert, Sask.	1,450	28.48	30.07	+.12	47.1	−0.5	60.2	34.0	85	19	1.10	−0.16	0.4
Battleford, Sask.	1,592	28.27	30.01	+.09	48.9	−2.1	63.5	34.3	86	17	0.95	−0.67	1.0
Edmonton, Alb.	2,150												
Kamloops, B. C.	1,262												
Victoria, B. C.	230	29.82	30.08	+.08	52.2	−0.3	58.9	45.6	70	42	0.95	−0.53	0.0
Barkerville, B. C.	4,180												
Estevan Point, B. C.	20												
Prince Rupert, B. C.	170												
Hamilton, Ber.	151	30.12	30.28	+.22	72.2	+2.8	78.2	66.2	82	60	2.74	−1.92	0.0

LATE REPORTS, MARCH, 1929

Yarmouth, N. S.	65	29.72	29.79	−.16	32.4	+1.6	39.0	25.8	51	6	4.12	−0.88	21.4
Father Point, Que.	20	29.80	29.83	−.07	23.5	+3.2	31.5	15.5	44	−9	2.30	−0.43	23.0
Winnipeg, Man.	760	29.03	29.89	−.20	23.6	+11.3	33.2	14.0	62	−18	1.28	+0.25	9.4
Medicine Hat, Alb.	2,144	27.47	29.75	−.25	35.4	+7.9	45.9	24.9	67	5	0.18	−0.58	1.8
Calgary, Alb.	3,428	26.20	29.82	−.13	33.3	+7.1	45.3	21.3	61	1	0.54	−0.18	5.4
Banff, Alb.	4,521	25.18	29.83	−.11	30.7	+10.5	41.1	20.3	52	4	1.13	−0.26	10.0
Edmonton, Alb.	2,150	27.45	29.77	−.19	29.4	+5.2	38.8	20.1	53	−7	0.78	+0.06	2.1
Kamloops, B. C.	1,262	28.60	29.91	−.01	41.3	+5.2	50.5	32.2	61	25	1.12	+0.55	0.5

LATE REPORTS, APRIL, 1929

Sydney, C. B. I.	48	29.88	29.93	+.04	34.6	−0.4	42.3	26.9	61	16	4.22	+0.37	16.0
Halifax, N. S.	88	29.83	29.94	−.02	38.4	+0.6	46.3	30.5	60	20	6.79	+2.61	4.0
Yarmouth, N. S.	65	29.78	29.85	−.11	39.0	+0.1	45.4	32.6	58	24	4.50	+0.63	16.4
Charlottetown, P. E. I.	38	29.82	29.86	−.04	35.5	+0.3	40.9	30.0	57	20	1.92	−0.78	2.5
Chatham, N. B.	28	29.80	29.83	−.07	34.8	−0.7	43.1	26.6	67	17	3.43	+0.80	0.3
Father Point, Que.	20	29.88	29.90	−.03	32.3	−0.9	39.7	25.0	65	10	4.66	+3.08	38.2
Winnipeg, Man.	760	29.09	29.93	−.09	40.1	+4.2	50.2	30.1	66	14	1.13	+0.08	1.3
Medicine Hat, Alb.	2,144	27.54	29.81	−.11	39.6	−4.9	51.4	27.8	70	4	2.44	+1.70	13.1
Calgary, Alb.	3,428	26.28	29.89	−.01	35.8	−3.8	48.6	23.0	71	8	1.42	+0.78	14.2
Banff, Alb.	4,521	25.24	29.88	−.02	32.2	−3.1	44.0	20.5	65	−3	1.50	+0.42	12.0
Kamloops, B. C.	1,262	28.59	29.89	−.04	46.4	−2.5	57.1	35.7	76	19	0.76	+0.37	0.6
Barkerville, B. C.	4,180	25.52	29.87	+.01	29.3	−3.8	39.1	19.5	54	−10	2.76	+0.94	23.4
Estevan Point, B. C.	20				42.0		48.8	35.2	56	27	7.35		7.8
Prince Rupert, B. C.	170				42.0		49.9	34.2	65	22	2.24		9.6
Hamilton, Ber.	151	30.00	30.16	+.11	67.2	+3.3	73.0	61.4	78	54	3.24	−0.94	0.0

Chart I. Departure (°F.) of the Mean Temperature from the Normal, May, 1929

Chart I. Departure (°F.) of the Mean Temperature from the Normal, May, 1929

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Chart II. Tracks of Centers of Anticyclones, May, 1929. (Inset) **Departure of Monthly Mean Pressure from Normal**

(Plotted by Gordon E. Dunn)

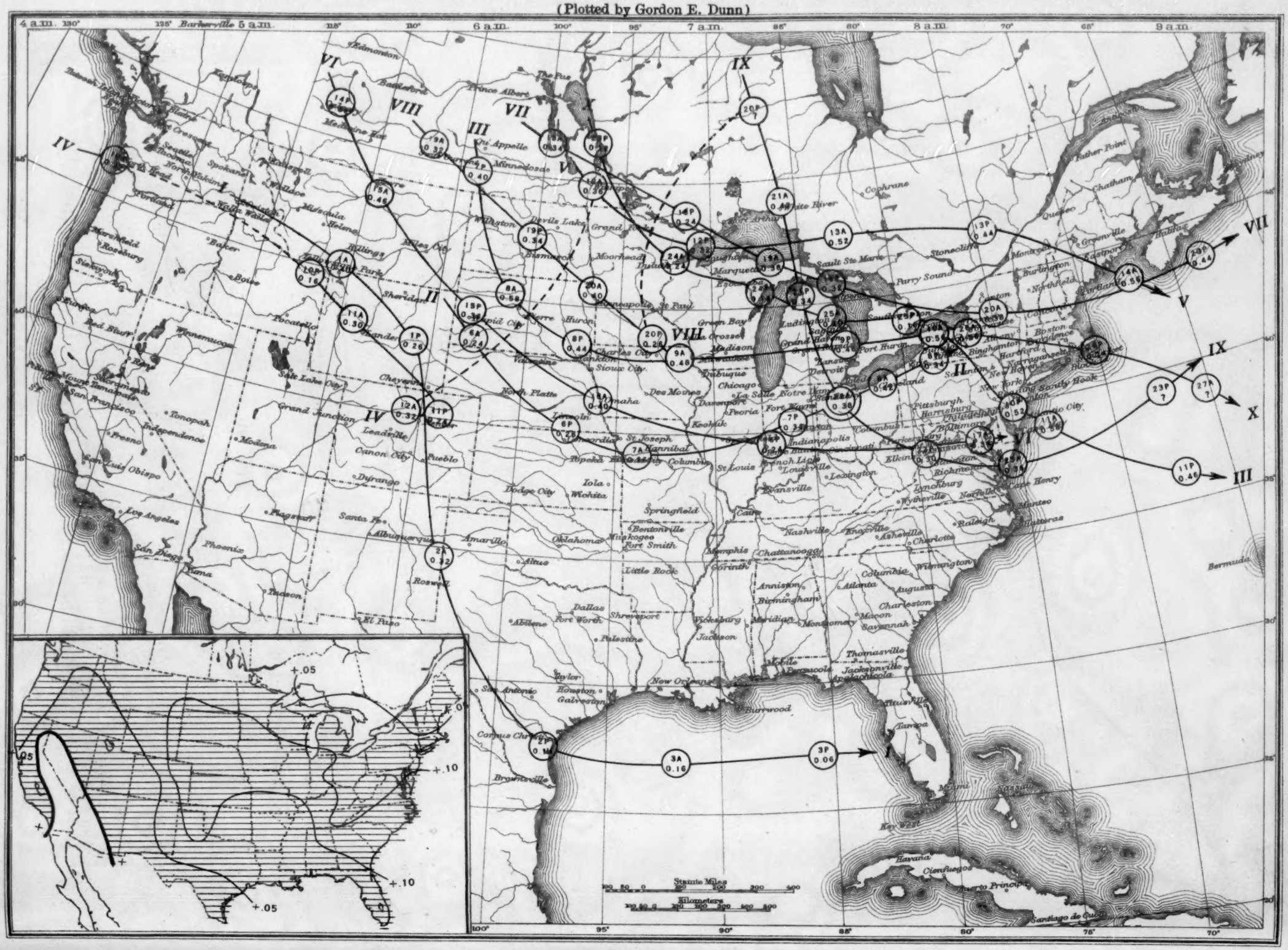


Chart III. Tracks of Centers of Cyclones, May, 1929. (Inset) **Change in Mean Pressure from Preceding Month**

(Plotted by Gordon E. Dunn)

Chart III. Tracks of Centers of Cyclones, May, 1929. (Inset) Change in Mean Pressure from Preceding Month
(Plotted by Gordon E. Dunn)

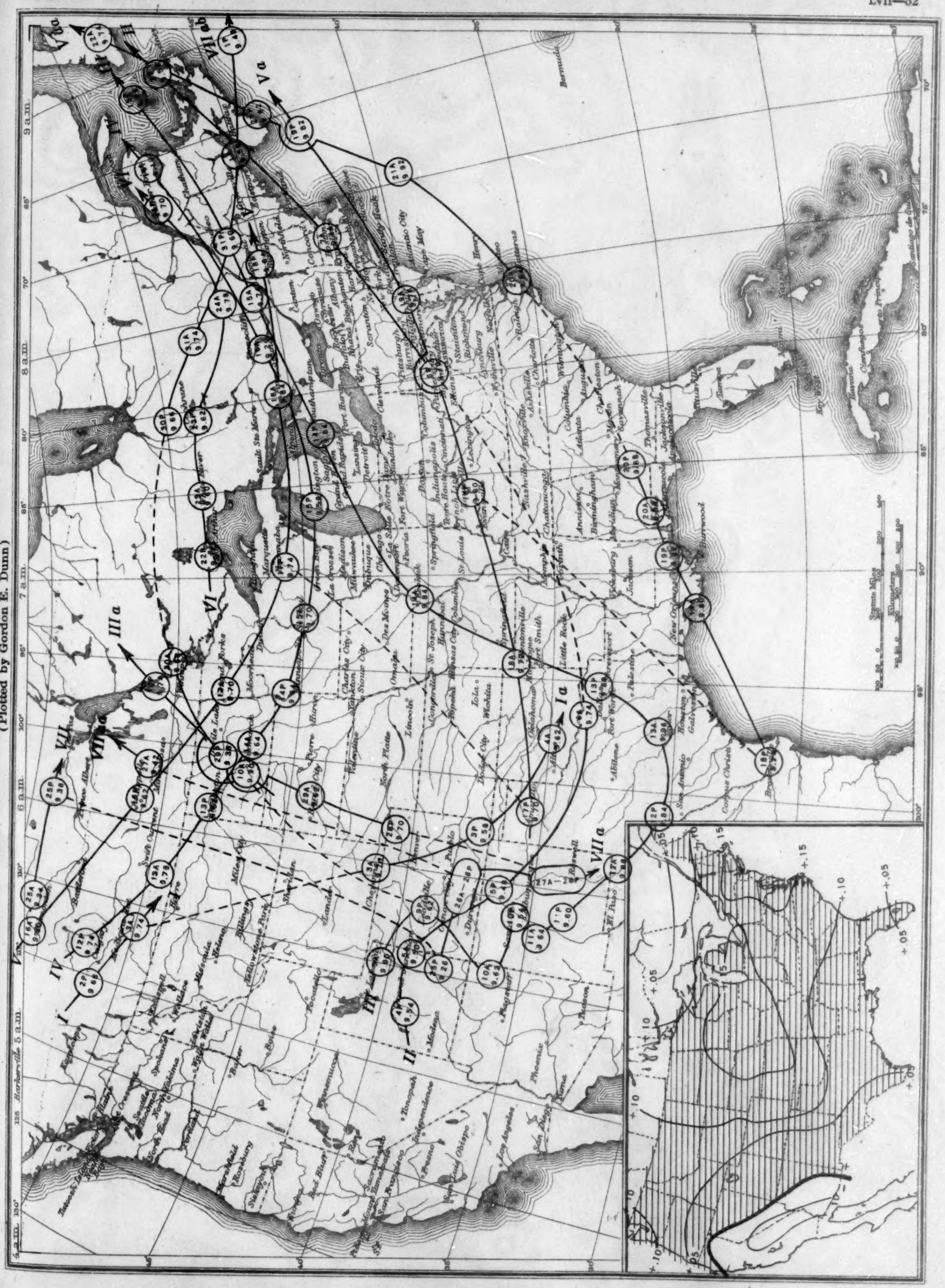
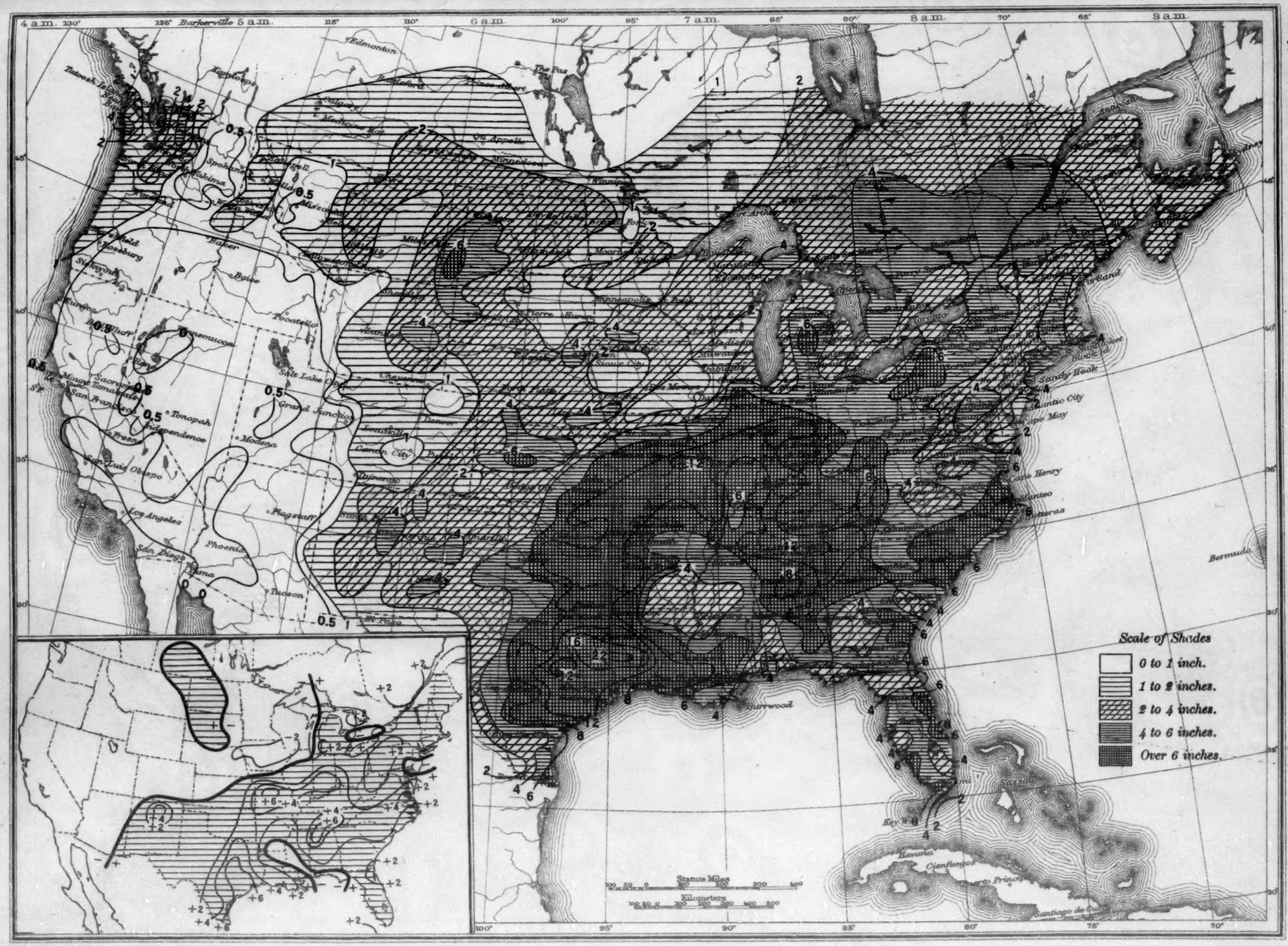

Ia
II
IIa
IIb
III
IIIa
IV
V
Va
VI
VIa
VII
VIIa
VIIb
VIII
VIIIa
Barbadoes
Bermuda
Key West
Tampa
Jacksonville
Charleston
Savannah
Atlanta
Birmingham
Montgomery
Vicksburg
Jackson
New Orleans
Mobile
Pensacola
Thomasville
Augusta
Columbia
Charlotte
Asheville
Raleigh
Norfolk
Cape May
Atlantic City
Wilmington
Baltimore
Washington
Philadelphia
Harrisburg
Pittsburgh
Altoona
Johnstown
Scranton
Binghamton
Elmira
Rochester
Buffalo
Erie
Toledo
Cleveland
Detroit
Port Huron
Grand Rapids
Saginaw
Lansing
Battle Creek
Kalamazoo
Muskegon
Milwaukee
Racine
Kenosha
Chicago
South Bend
Fort Wayne
Indianapolis
Terre Haute
Evansville
Cincinnati
Columbus
Springfield
Dayton
Zanesville
Wheeling
Parkersburg
Huntington
Charleston
Lexington
Louisville
Nashville
Chattanooga
Knoxville
Memphis
Little Rock
Fort Smith
Hannibal
St. Joseph
Kansas City
Topeka
Omaha
Lincoln
Des Moines
Davenport
Rock Island
Peoria
Springfield
St. Louis
Cairo
Paducah
Evansville
Terre Haute
Indianapolis
Fort Wayne
Toledo
Cleveland
Erie
Buffalo
Rochester
Syracuse
Albany
Utica
Binghamton
Scranton
Harrisburg
Pittsburgh
Altoona
Johnstown

Chart IV. Percentage of Clear Sky between Sunrise and Sunset, May, 1929

May, 1929. M. W. R.

Chart V. Total Precipitation, Inches, May, 1929. (Inset) Departure of Precipitation from Normal

Chart V. Total Precipitation, Inches, May, 1929. (Inset) Departure of Precipitation from Normal



May, 1929. M. W. R.

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Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, May, 1929

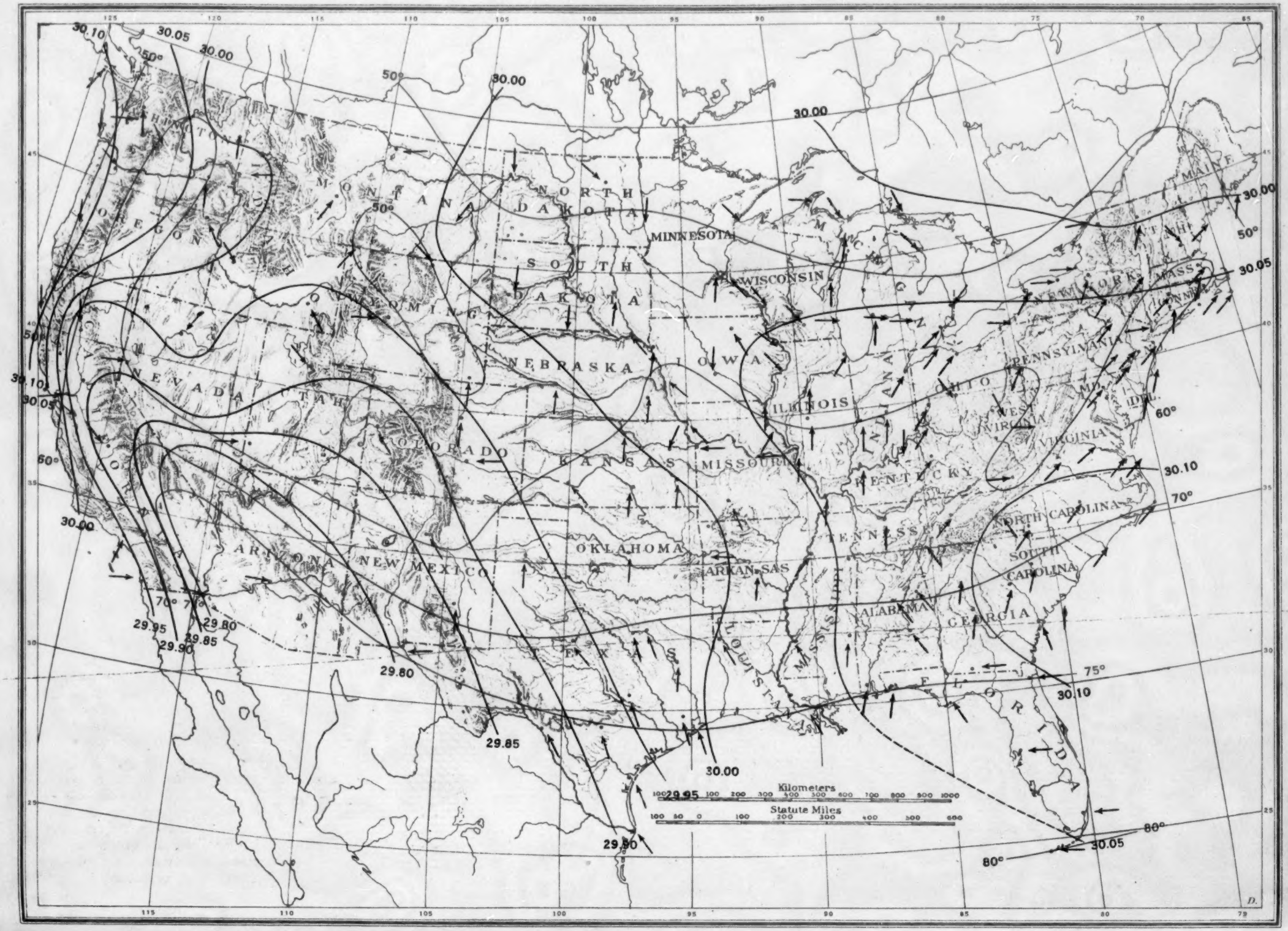

Chart VIII. Weather Map of North Atlantic Ocean, May 13, 1929

(Plotted by F. A. Young)

Chart VIII. Weather Map of North Atlantic Ocean, May 13, 1929

(Plotted by F. A. Young)

Greenwich Mean Noon.

Isobars show corrected barometric readings in inches of mercury.

Arrows fly with the wind.

Number of feathers indicate force, Beaufort scale.

Weather symbols are as follows:

○ clear, ◑ partly cloudy, ● cloudy, ⁝ rain, ▲ hail or sleet, ✳ snow, ≡ fog.

Pointed arrows indicate land stations.

Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.

Chart IX. Weather Map of North Atlantic Ocean, May 14, 1929

(Plotted by F. A. Young)

Greenwich Mean Noon.

Isobars show corrected barometric readings in inches of mercury.

Arrows fly with the wind.

Number of feathers indicate force, Beaufort scale.

Weather symbols are as follows:

○ clear, ◑ partly cloudy, ● cloudy, ⁝ rain, ▲ hail or sleet, ✳ snow, ═ fog.

Pointed arrows indicate land stations.

Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.

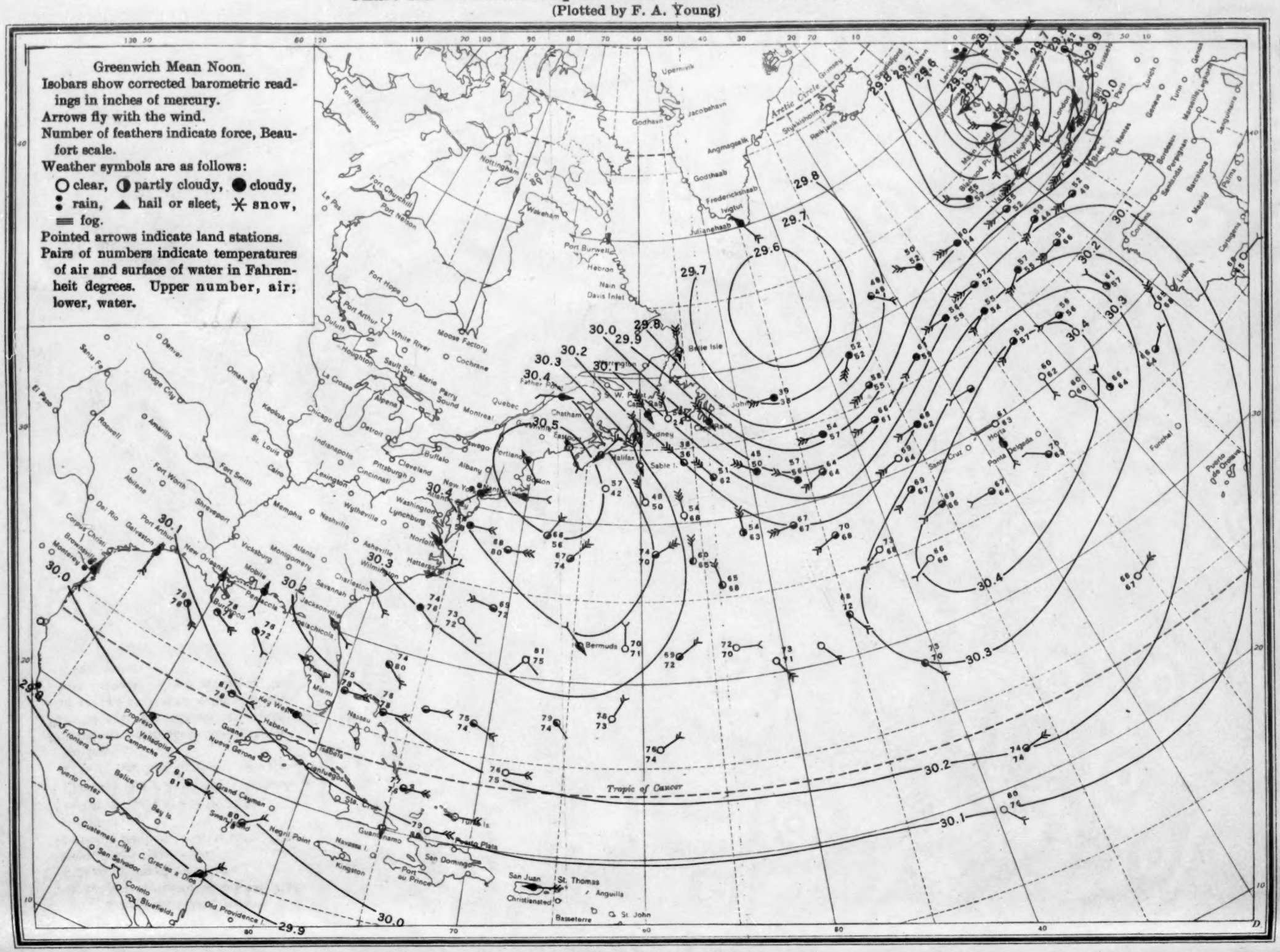

Chart X. Weather Map of North Atlantic Ocean, May 15, 1929

(Plotted by F. A. Young)

Chart X. Weather Map of North Atlantic Ocean, May 15, 1929

(Plotted by F. A. Young)

Greenwich Mean Noon.

Isobars show corrected barometric readings in inches of mercury.

Arrows fly with the wind.

Number of feathers indicate force, Beaufort scale.

Weather symbols are as follows:

○ clear, ◑ partly cloudy, ● cloudy, ⁝ rain, ▲ hail or sleet, ✳ snow, ═ fog.

Pointed arrows indicate land stations.

Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.

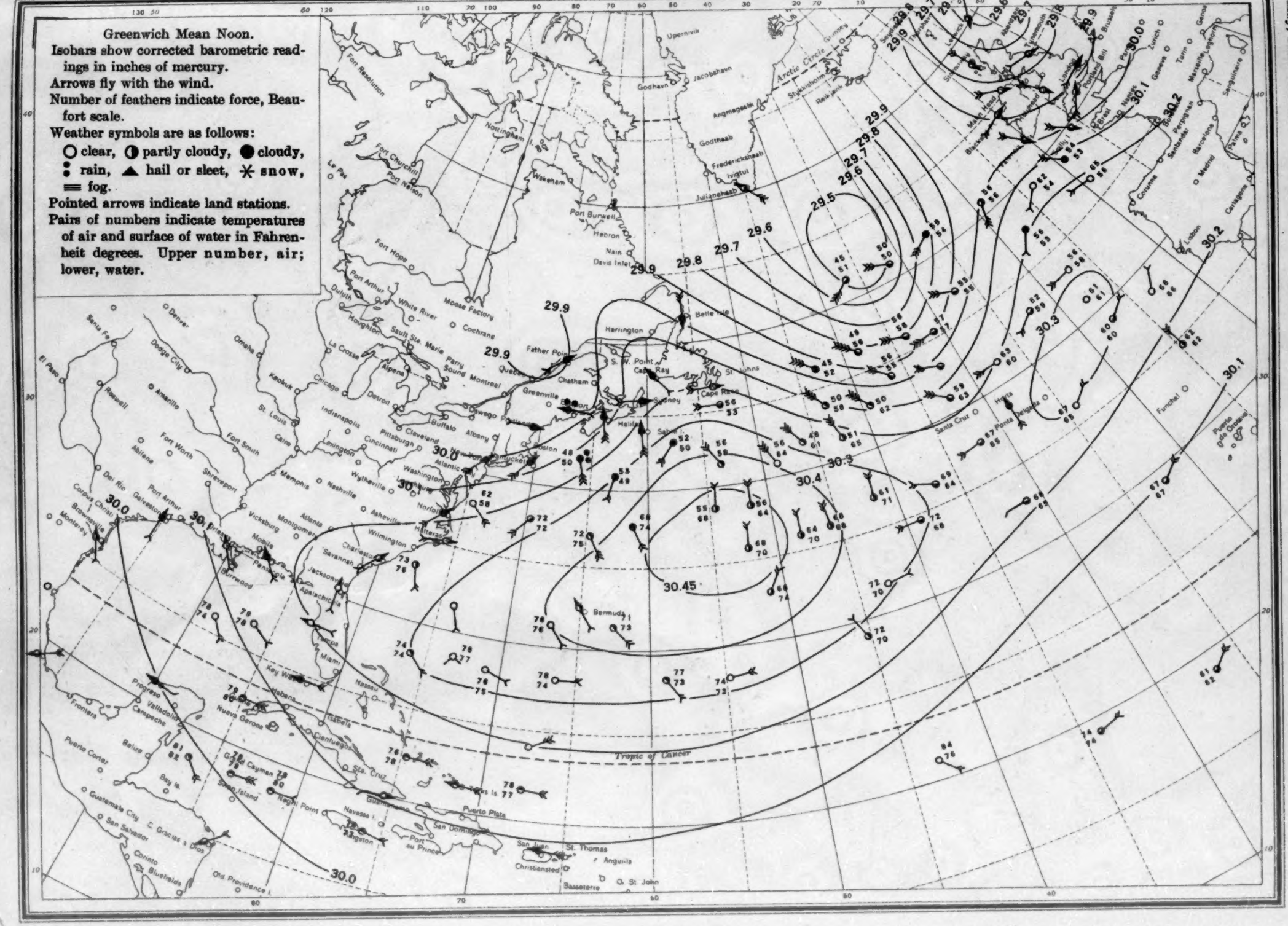

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Chart XI. Weather Map of North Atlantic Ocean, May 16, 1929

(Plotted by F. A. Young)

Greenwich Mean Noon.

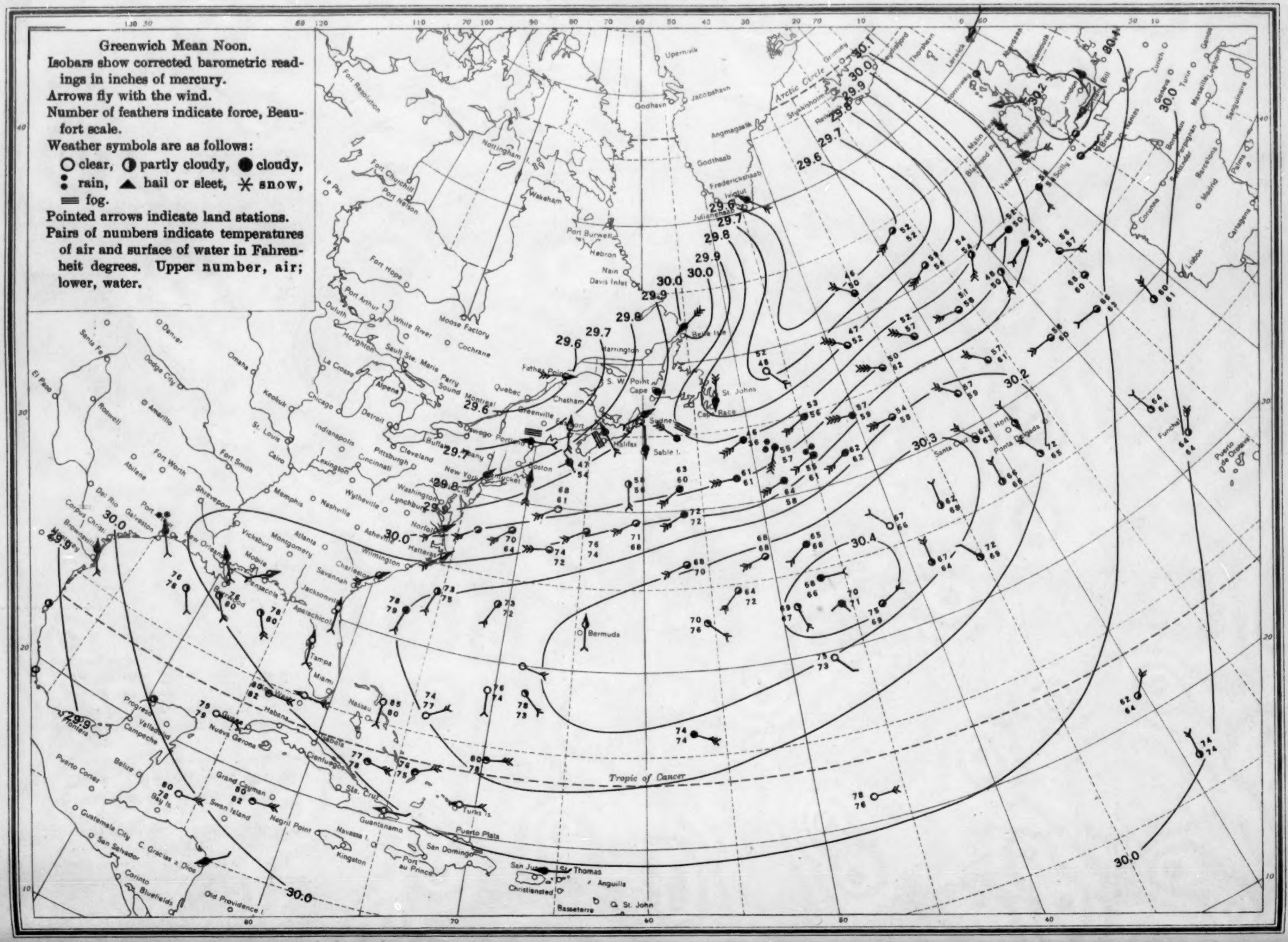
Isobars show corrected barometric readings in inches of mercury.

Arrows fly with the wind.

Number of feathers indicate force, Beaufort scale.

Weather symbols are as follows:

○ clear, ◑ partly cloudy, ● cloudy, ⁝ rain, ▲ hail or sleet, ✳ snow, ═ fog.

Pointed arrows indicate land stations.

Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.